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THE JAPANESE BEETLE[1]

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INTRODUCTION

During the summer of 1916 E. L. Dickerson and H. B. Weiss, of the New Jersey State Department of Agriculture, collected a few beetles in a nursery near Riverton, N. J., of a species with which they were not familiar. These insects were later identified by E. A. Schwarz, of the Bureau of Entomology, as being the same as a

[1] The Japanese beetle project is organized as a cooperative undertaking and funds for its support are contributed by the Bureau of Entomology of the United States Department of Agriculture and the States of New Jersey and Pennsylvania. The direction of the project as a whole lies with a committee composed of representatives of the several cooperating agencies: A. L. Quaintance and Loren B. Smith (the latter representing the laboratory force), of the Bureau of Entomology, for the United States Department of Agriculture; T. J. Headlee, State Entomologist of New Jersey, for the New Jersey Department of Agriculture; and Charles H. Hadley, Director of the Bureau of Plant Industry, for the Pennsylvania Department of Agriculture. The main office and laboratories are situated just outside the town of Riverton, Burlington County N. J., in the heart of the infested territory. Substations are established at Philadelphia and Holmesburg, Philadelphia County, Pa., and temporary summer stations have been maintained in both States as required. The work is divided into distinct lines: Administration, with the senior writer in charge of the project as a whole; quarantine enforcement. in charge of C. W. Stockwell, the Federal Horticultural Board assuming administrative supervision of the Federal quarantine, and the Bureau of Entomology fiscal supervision and actual enforcement; soil-insecticide investigations, in charge of B. R. Leach; biological and parasite investigations, in charge of J. L. King; beetle-insecticide investigations, in charge of E. R. Van Leeuwen; and spraying and field work, in charge of A. R. Whitcraft. The parasite investigations in India, China, and Japan are in charge of C. P. Clausen, H. A. Jaynes, and T. R. Gardner.

The data included in this circular have been collected by various workers, including the writers, at the Japanese Beetle Laboratory, Riverton, N. J., since the Japanese beetle project was started in 1917. The writers have also drawn freely from the papers on the Japanese beetle by J. J. Davis, who was formerly in charge of the project. Other data have been taken from unpublished notes made by T. H. Frison and Henry Fox, members of the laboratory force in the last several years.

[2] Resigned October 9, 1923, to accept the position of Director of the Bureau of Plant Industry, Pennsylvania Department of Agriculture.

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species locally common on the islands of Japan, but new to and not heretofore occurring in the United States. Thus the species came to be known as the Japanese beetle (*Popillia japonica* Newm.). In all, only about a dozen of the beetles were found in Riverton that year. From the time of its discovery this insect has increased in numbers and spread at a relatively rapid rate in New Jersey and Pennsylvania, until at the close of the summer of 1923 the total area known to be infested amounted to about 2,442 square miles. As yet, the beetle has not been found outside of this unit area.

Little was known concerning the habits of this insect in Japan, and there was almost no information available indicating whether or not it would prove to be a serious pest. Efforts were made at that time, with the limited funds available, to exterminate the insect by various means, including spraying its food plants with heavy applications of arsenical sprays and treating the sod-lands with cyanide. These measures may have served as a temporary check on the distribution of the insect, but it continued to spread until it reached the point where eradication or extermination became almost an impossibility. Not only would such a program have involved a huge expenditure of money and caused serious economic loss, but many fundamental difficulties were encountered even in finding a means of killing the insect on a large scale. The problem resolved itself into one of working out practical measures of artificial control, preventing the spread by restricting the movement of products likely to carry the insect, and the importation of parasites and diseases found in its native home, which upon their establishment in this country might play an important part in the natural control of the Japanese beetle.

It is now evident why the Japanese beetle has been so successful in establishing itself in this country. The adult beetle is almost omnivorous, attacking many important crops, such as the fruit and foliage of the apple and peach, cherry, grape, beans, clover, alfalfa, and sweet corn, in addition to various shade and ornamental trees, shrubs, and herbaceous plants. Since the insect is a strong flier and is exceedingly active on warm days, its normal spread from year to year has been fairly uniform. The fewness of its natural enemies has permitted the beetle to reproduce in almost incredible numbers, while climatological, ecological, and cultural conditions in the infested areas have been remarkably suitable for its development, and there is every reason to believe that this insect is now firmly established in the United States; on the other hand, seven years of observation and experience have shown that it can be and is being successfully controlled in the area where it has occurred for the longest time.

Brief accounts of the Japanese beetle have been published from time to time, as well as a number of technical papers by various members of the laboratory staff. This circular has been prepared for the purpose of presenting the general features of the Japanese beetle problem as a whole, to supplement the strictly technical papers dealing with limited phases of the subject, and to discuss the progress which has been made in the control of this newly introduced pest.

DISTRIBUTION

There are 264 known species in the subtribe Popilliiana; of these, 219 belong to the genus Popillia. The species are distributed widely throughout the Philippine Islands, Java, Formosa, Sumatra, and the islands included in the Malay Archipelago. They also occur in abundance throughout Cochin China, Siam, Japan, eastern China, Bengal, eastern and northern India, Nepal, Assam, and western China. Seventy-nine species have been recorded in India. One species occurs in Rumania, one in Turkey, and two in the Crimean region of Russia. The group is well represented in Africa, a large number of species having been recorded in east Africa, Abyssinia, and Congo, with scattering species occurring as far south as the Cape Colony district. Other species have also been recorded in the countries on the west coast of Africa, particularly Kamerun, Nigeria, Ashanti, Togo, Sierra Leone, Senegal, and French Sudan. Three species are known to occur in Algeria and two in Tripoli, and five have been reported from Egypt. Except where they have been introduced, no representatives of this subtribe are found in North America or South America. As a group, these insects are tropical in their occurrence, since the majority of the species are distributed between the Equator and 20° north and south latitude. A few, however, notably those which occur in Japan and Manchuria, are found between 50 and 55° north latitude. In northern India most of the species are found between 28 and 38° north latitude and at elevations of 1,500 to 7,500 feet. Several species have been reported as being of economic importance in various countries, particularly *Popillia hilaris* Kraatz, which causes considerable injury to cotton in British East Africa. *Popillia biguttata* Weil has been recorded as causing injury to tea, coffee, and other plants in Java.

The native home of *Popillia japonica* Newman is the main islands of Japan. The occurrence of this insect in continental Asia has not been positively determined. *P. atrocoerulea* Bates occurs in northern China and Korea and has been confused with *P. japonica* by some entomologists. *P. japonica*, variety *plectipennis*, which was described from Japan, has also been reported from Borneo. There is some question, however, whether the *plectipennis* described from Borneo is identical with the *plectipennis* from Japan.

On the Japanese islands of Kyushiu and Shikoku the Japanese beetle is common but not abundant, and in Hondo, from Yokohama northward, the beetles are usually more numerous. In Saitama, Tachiga, and Fukushima Kens, where the soybean is one of the principal crops, the species is at times numerous enough to cause some damage. Farther north, at Morioka, the infestation is often heavy, but the preference for certain weeds, particularly the itadori (*Polygonum reynoutria*), which grows wild along the roadsides, has prevented serious damage to crops of economic importance. The beetles occur generally throughout the island of Hokkaido. Here, as in the northern portion of Hondo, the crops grown are similar to those in our North-Central States. Damage to crops by the beetles sometimes occurs in these regions.

The beetle is not considered a serious pest in Japan, probably owing to the presence there of native parasites and to the fact that

it does not have either the large areas suitable for its reproduction and development or the abundant supply of food which it finds in the eastern part of the United States. Furthermore, the areas in Japan, except in the northern islands, which are most suited for the development of the larvæ, are intensively cultivated, and little opportunity is found for the species to reproduce in large numbers. Upon its introduction into New Jersey the species found particularly favorable conditions for development and an abundant supply of food; these, together with the absence of its parasites, have enabled it to increase rapidly until at present it has reached a point where its injuries are becoming of serious economic importance.

INTRODUCTION AND SPREAD

It is believed that the Japanese beetle came into the United States as larvæ in the soil about the roots of certain nursery plants, presumably azalea or Japanese iris. All information indicates this as the most probable method of its introduction. The comparatively short existence of the insect as an egg, pupa, or adult, the relatively long period as a larva in the soil, and the season of year in which shipments from Japan to this part of the United States are commonly made, furnish a basis for this assumption. The further fact that larvæ of closely related species are known to have been brought to America in soil about the roots of plants from Japan (*1*)[3] indicates that the introduction was probably in the grub stage.[4]

This belief is further substantiated by the fact that living larvæ of *Popillia japonica* have many times been found in the soil about the roots of coniferous and other types of nursery stock in infested nurseries within the Japanese beetle territory, and in similar plants used in connection with certain experiments; also in potted stock exposed to infestation during the period of beetle abundance.

It is difficult to say definitely in what year the introduction occurred. It is known that nursery stock with soil about the roots was imported prior to 1912 into the vicinity where the infestation was first discovered, and the indications are that a few larvæ of the Japanese beetle were introduced about that time. Undoubtedly a very few larvæ were sufficient for the establishment of the pest in this country.

Since the insect was originally discovered it has spread steadily in all directions. This dispersion is the result not only of the natural tendency of the insect to move outward in search of food and suitable breeding places, as the density of infestation increases year by year, and to be carried by such natural agencies as winds and waterways, but also of transportation through the agency of men. The latter is brought about by the movement of farm products of various kinds from the heavily infested districts, by the passage of vehicles of all sorts, and by pedestrians along the roads through the more densely infested portions.

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[3] Figures in italics in parentheses refer to "Literature cited," p. 66.

[4] L. A. Strong, of the Federal Horticultural Board, has stated in correspondence that living larvæ of either the Popillia group or related groups have been taken during the course of inspection from the soil about the roots of plants imported from Japan in earlier years, and similar occurrences have been reported in correspondence with the writer by L. S. McLaine, of the Canada Department of Agriculture.

In 1916 the area found to be infested was estimated to be less than 1 square mile in extent. At this time the beetles were found feeding on the tips of Crataegus. It was assumed to be a southern species, and no particular efforts were made to determine the exact limits of the area infested. Since comparatively few beetles were found it is probable that the area infested was relatively small, certainly not more than the figure given above.

During the summer of 1917 a considerable area was scouted and the infestation was found to cover approximately 2.7 square miles, of which about 0.5 square mile was heavily infested.

In 1918 the infestation was found to have increased to include an area of approximately 6.7 square miles. Until that year the numbers of the insect were still comparatively small, and the spread can not be considered especially extensive in comparison with the spread of later years.

The number of the insects in the heavily infested area had in 1919 increased to such a degree that in the center of the infested territory beetles could be found in abundance. During the summer of 1919 the spread was considerable, and a total of 48.3 square miles was found to be infested. No Japanese beetles had then been found across the river in Pennsylvania.

There was again a large increase in infested territory during 1920, and for the first time beetles were found in Pennsylvania. It is probable, however, in view of the numbers found there during that season, that the insect had actually reached the Pennsylvania side of the Delaware River during the preceding season (1919), but in numbers so small as not to have been observed in the scouting. At the end of 1920 the infested area in New Jersey was 92 and in Pennsylvania 11 square miles, a total of 103 square miles.

The outward spread in 1921 was greater than had occurred at any previous time. During 1920, and to a less extent in the preceding summer, strenuous efforts to prevent the spread of the insect had been made by a program of dusting and spraying around the infested area. The spread which occurred, however, especially during the seasons of 1919 and 1920, seemed to show that repressive measures as followed were not sufficiently effective to justify their continuation. During the summer of 1921 the beetles had increased in numbers to a very marked extent, and there was an increase in infested area probably in direct proportion to the increase in density. At the end of this season the infested area in New Jersey amounted to 213.5, and in Pennsylvania to 56.5 square miles, a total of 270 square miles.

During the season of 1922 there was an increase in both density and area of infestation. The spread was fairly general in all directions and gave a total infested area, including portions of both Pennsylvania and New Jersey, of 773 square miles.

The greatest spread of the beetle to the present time occurred in 1923. The infestation spread across the pine barrens in central New Jersey and reached the coast at various points between Barnegat City and Ocean City. How firmly the insect will become established in the dry, sandy pine-barren region is, of course, problematical. In Pennsylvania the outward movement extended between 10 and 15 miles beyond the limits of 1922. No evidence was gathered which would indicate that the lower-lying hills in eastern Pennsylvania

offered any material check to the natural dispersion of the insect. At the end of the season of 1923 it was found that the territory infested by the Japanese beetle amounted to 2,442 square miles. The area infested in Pennsylvania is approximately 698 square miles, and in New Jersey the area was increased to 1,744 square miles.

Plate I illustrates in map form the spread of the Japanese beetle from 1916 to 1923, as described in preceding paragraphs. Figure 1 is a chart showing for the seasons of 1922, 1923, and 1924 the time and rate of emergence, period of maximum abundance, and time and rate of decline in the number of Japanese beetles. The relative values expressed by the vertical scale are percentages of the maximum abundance for the season to which the curve for any year relates: It should be noted that during the seasons of 1923 and 1924 the beetles were abundant for a much shorter period than during the season of 1922. According to the data obtained, the maximum

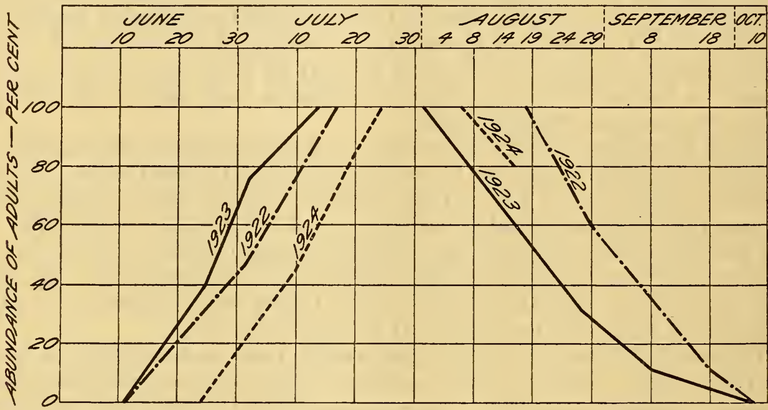


FIG. 1.—Time and rate of emergence, period of maximum abundance, and time and rate of decline of Japanese beetle in the seasons of 1922, 1923, and 1924

abundance of the beetles lasted over a period of only 12 days in 1924, in marked contrast with a period of more than 30 days during which the maximum abundance lasted in 1922.

THE INFESTED AREA IN THE UNITED STATES

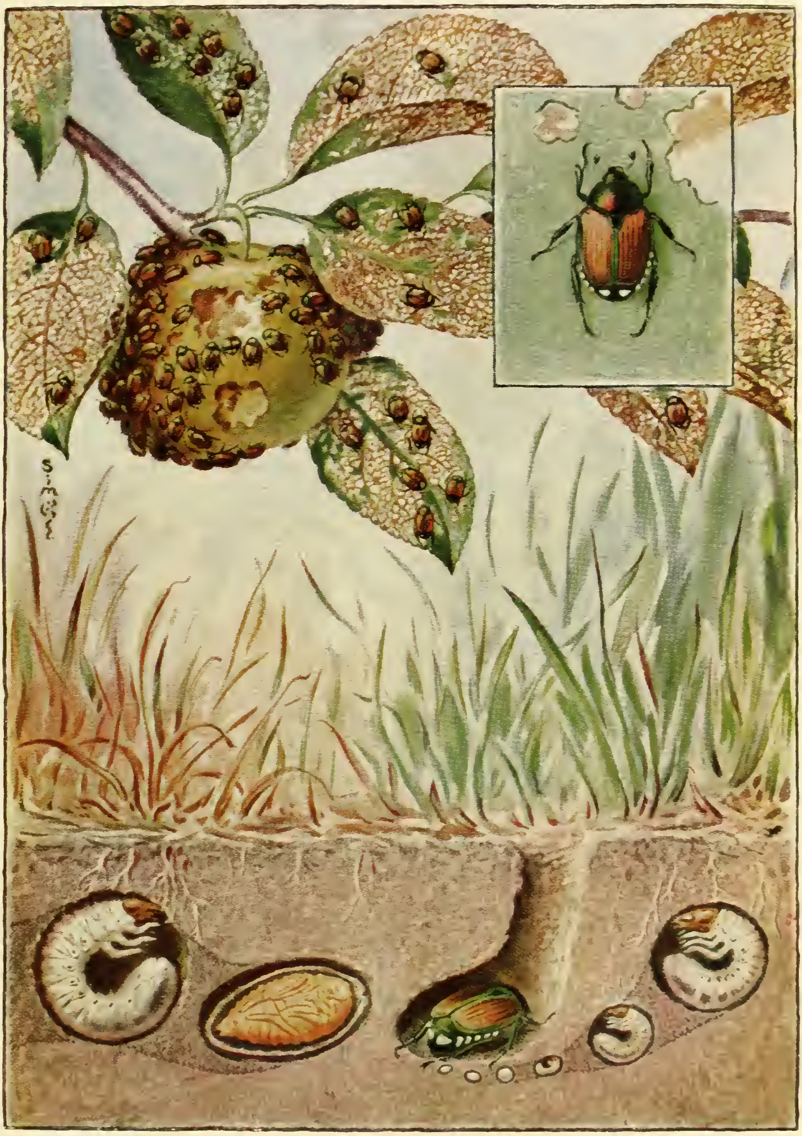
The region into which the Japanese beetle was introduced has apparently offered ideal conditions for the rapid multiplication of the species. It therefore seems advisable to give a brief description of the physiography of the area.

As has already been stated, the beetle is now to be found in the western and central parts of New Jersey and in eastern Pennsylvania in an area about 2,500 square miles in extent; and the region in which it occurs or into which there is imminent danger of its spreading includes parts of two general physiographic provinces, the Piedmont Plateau and the Coastal Plain.

The Piedmont Plateau, although a region of varied topography, is one of relative uniformity in its faunal and floral features, hence subdivisions of a biological nature are not readily distinguishable.

Map showing the annual

Map showing the annual spread of the Japanese beetle from 1916 to 1923. The infested area in square miles for each year was as follows: 1917, 2.7; 1918, 6.7; 1919, 48.3; 1920, 103.2; 1921, 270.1; 1922, 773; 1923, 2.440



JAPANESE BEETLE (*Popillia Japonica*)

The beetle deposits its egg in the soil. The larvæ, or grubs, hatching from them, feed on grass roots and decaying vegetable matter until autumn, when they become full grown. No feeding occurs during the winter, but in the spring the grubs feed for about a month before transforming to the tan-colored pupæ. These change to the adults, or beetles, and emerge about the middle of June. The beetles cause damage by feeding on foliage and fruit. The grubs cause serious injury to sod lands through the damage which they inflict on the roots of grasses. Stages in soil, and inset, somewhat enlarged; beetles on foilage and fruit much reduced

On the other hand, the Coastal Plain region, although in general characterized by monotonous uniformity as regards topography, is one in which remarkable contrasts prevail in its faunal and floral features.

The Piedmont Plateau occupies all of southeastern Pennsylvania with the exception of a narrow strip along the Delaware River. In New Jersey it forms the country lying north of a line extending between Trenton and Jersey City. It is prevailingly a region of moderate altitudes, though relatively high as compared with the Coastal Plain, its surface varying in southeastern Pennsylvania, adjacent to Philadelphia, from about 200 to 600 feet above sea level. Certain of the streams traversing the region have cut their channels considerably below these altitudes. In general, the district is one of considerable relief, the surface being all of a rolling type, rather gentle on the upland, more or less broken in the wider valleys, and precipitous near the streams.

In marked contrast to the Piedmont area, the Coastal Plain in this section is a region of low elevation, gentle relief, and frequently, in its more central portions, of imperfect drainage. Its surface rarely exceeds 200 feet in elevation, and is in general very much lower than this, the maximum being reached on only a few isolated hills in the central part. Unlike the Piedmont section, the Coastal Plain is underlain by soft and incoherent deposits belonging to the Cretaceous and Miocene formations. In general, soils of fine texture predominate and are of the highest agricultural value. These are best developed in the immediate vicinity of the Delaware River. In the interior, especially in the section known as the Pine Barrens, coarse siliceous soils are of almost universal occurrence.

The Japanese beetle was introduced into the central portion of what has been termed "the middle district" of the New Jersey Coastal Plain region, but at the close of the season of 1923 it had spread across the Coastal Plain into the Piedmont Plateau region in Pennsylvania in the west and extended its range across the Pine Barrens to the Atlantic coast in the East.

The spread of the beetle is obviously favored by the prevalence of a type of environment closely in accord with its needs, chief among these being food and soil requirements. It is known that the beetles are capable of feeding upon a great variety of cultivated plants, although most of the preferred species are hydrophytes or mesophytes. This being the case it must be assumed that their spread is favored in sections where hydrophytic and mesophytic vegetation is prevailing; whereas it is reasonable to suppose that it would be stopped or at least retarded in sections in which extensive xerophytic conditions are dominant.

The food requirements of the grubs of the Japanese beetle have been determined, and from the observations made it is indicated that they are best met in soils with a generous cover of herbaceous vegetation, particularly where there is a permanent or semipermanent sod.

It is evident that the soil must be of such character in its texture, moisture conditions, and chemical reaction as to permit growth of the vegetation furnishing food to the beetle and its larva. Such vegetation is prevailingly of a mesophytic character, and it would

seem probable that such soils as loams, which allow a ready draining of rain water but do not allow it to escape too rapidly, would be favorable to the Japanese beetle, whereas very porous soils, including coarse sands and gravel, together with the highly impervious types such as stiff clays, would be detrimental to the development of the species.

The moisture content of the soil is not only important as a source of water for plant growth, but it is necessary also from the standpoint of the requirements of the larvæ. On the other hand, extreme conditions, as in the case of a very dry soil or one which is perpetually saturated with water, would at least retard, if not prohibit, the successful development of the grubs. It is therefore to be expected that the Japanese beetle will not successfully establish itself on dry plains or in swamps or marshes, but will probably develop in most regions suited to agricultural purposes.

From a study of the soils in the region which is infested with the Japanese beetle, it has been found that they are neutral in reaction or at most slightly acid. This is the type best adapted for the development of the kind of vegetation furnishing the usual food plants of the species; and it would seem that the environment favorable to the Japanese beetle is an open campestral country, abundant in permanent sod-lands and weedy areas, and supporting a rich growth of hydrophytic and mesophytic vegetation.

ECONOMIC STATUS OF THE INSECT

Since its introduction, the insect has increased in numbers at an extremely rapid rate. In 1916 only a few beetles could be collected. By 1919 as many as 15,000 or 20,000 beetles could be hand collected by one person in a single day. During the summer of 1923 beetles were to be found in individual orchards by many thousands on the foliage and the fruit of various trees. This condition obtained not only in a single orchard but in many orchards throughout the heavily infested territory. As an example of how abundant the beetles were during this season, early one morning, while it was cool and the adult beetles more or less inactive, a large canvas was spread under each of one hundred and fifty-six 10-year-old peach trees; the trees were shaken vigorously and the inactive beetles, instead of flying to other plants, as they would have done later in the day, dropped to the canvas and were collected. In a little over two hours 208 gallons of beetles, or 1⅓ gallons of beetles to each tree, were collected. On examination 24 hours later it was found that, in spite of the removal of the beetles during the previous day, the trees were about as heavily infested as they had been the previous morning. Besides attacking the foliage, the insects feed on the fruit and are found clustered on apples and peaches in large numbers. As many as 278 beetles have been collected on a single apple.

During the fall of 1923 larvæ were found to be extremely numerous in some locations; for example, on one of the greens in the local golf course they were found as abundant as 1,531 to the measured square yard. In pastures the infestation was found to be as high as 717 larvæ to a square yard. An average condition of infestation throughout the heavily infested area during the fall of

1923 was found to be about 175 larvæ to the square yard in sod lands, as compared with 122 larvæ to the square yard in similar locations in the spring of the same year.

FOOD PLANTS OF THE JAPANESE BEETLE IN NEW JERSEY

At the present time about 200 species of plants are recorded as furnishing food for the beetles in New Jersey. Practically all the economic crops grown in the infested territory are represented in the list, the most important of which are apple, quince, peach, sweet cherry, plum, grape, blackberry, clover, soybean, and corn; the shade trees attacked include linden, birch, oak, elm, sassafras, horse-chestnut, and willow; ornamental shrubs, particularly althaea and rose, flowers of all kinds, and weeds of many kinds are also attacked. In the following list those species most vigorously attacked are marked with an asterisk.

FOOD PLANTS OF THE JAPANESE BEETLE RECORDED IN NEW JERSEY

Polypodiaceae:
- Sensitive fern, *Onoclea sensibilis.*
- Maidenhair, *Adiantum* sp.
- Bracken, *Pteridium latiusculum.*

Ginkgoaceae:
- Maidenhair-tree, *Ginkgo biloba.*

Pinaceae:
- Arborvitae, *Thuja occidentalis.*

Typhaceae:
- Common cattail, *Typha latifolia.*

Alismaceae:
- Common arrowhead, *Sagittaria latifolia.*

Poaceae:
- Timothy, *Phleum pratense.*
- Rye, *Secale cereale.*
- Crabgrass, *Syntherisma sanguinalis.*
- *Indian corn, *Zea mays.*

Cyperaceae:
- Chufa, *Cyperus esculentus.*

Araceae:
- Virginia arrow-arum, *Peltandra virginica.*

Commelinaceae:
- Dayflower, *Commelina virginica.*
- Virginia spiderwort, *Tradescantia virginiana.*

Pontederiaceae:
- Pickerelweed, *Pontederia cordata.*

Liliaceae:
- Asparagus, *Asparagus officinalis.*

Iridaceae:
- German iris, *Iris germanica.*
- Rabbit-ear iris, *Iris laevigata.*
- Gladiolus, *Gladiolus* sp.

Cannaceae:
- *Canna, *Canna* sp.

Salicaceae:
- White poplar, *Populus alba.*
- Lombardy poplar, *Populus nigra italica.*
- *Babylon weeping willow, *Salix babylonica.*
- *Willow, *Salix* sp.

Juglandaceae:
- Mockernut, *Hicoria alba.*
- Shagbark hickory, *Hicoria ovata.*
- Butternut, *Juglans cinerea.*
- Japanese walnut, *Juglans sieboldiana.*
- Black walnut, *Juglans nigra.*

Fagaceae:
- *Alder, *Alnus* sp.
- *European white birch, *Betula alba.*
- Gray birch, *Betula populifolia.*
- American hazelnut, *Corylus americana.*
- *American chestnut, *Castanea dentata.*
- Japanese chestnut, *Castanea crenata.*
- American beech, *Fagus grandifolia.*
- European beech, *Fagus sylvatica.*
- Red oak, *Quercus borealis maxima.*
- Scarlet oak, *Quercus coccinea.*
- Pin oak, *Quercus palustris.*
- White oak, *Quercus alba.*
- Post oak, *Quercus stellata.*

Urticaceae:
- Red mulberry, *Morus rubra.*
- *American elm, *Ulmus americana.*
- India rubber tree, *Ficus elastica.*
- Hop, *Humulus lupulus.*

Polygonaceae:
- Buckwheat, *Fagopyrum vulgare.*
- Tear-thumb, *Polygonum arifolium.*
- Bindweed, *Polygonum convolvulus.*
- Bindweed, *Polygonum dumetorum cristatum.*
- Water pepper, *Polygonum hydropiper.*
- Ladysthumb, *Polygonum persicaria.*
- Princesplume, *Polygonum orientale.*

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Polygonaceae—Continued.
- *Smartweed, *Polygonum pensylvanicum.*
- Narrow dock, *Rumex crispus.*
- Bitter dock, *Rumex obtusifolius.*
- Rhubarb, *Rheum rhaponticum.*

Chenopodiaceae:
- Lambs-quarters, *Chenopodium album.*

Amaranthaceae:
- Pigweed, *Amaranthus* sp.
- Cockscomb, *Celosia cristata.*

Nyctaginaceae:
- Four-o'clock, *Mirabilis jalapa.*

Phytolaccaceae:
- Pokeberry, *Phytolacca americana.*

Caryophyllaceae:
- Corncockle, *Agrostemma githago.*

Ranunculaceae:
- Marsh crowfoot, *Ranunculus sceleratus.*

Berberidaceae:
- Japanese barberry, *Berberis thunbergii.*

Magnoliaceae:
- Southern magnolia, *Magnolia grandiflora.*

Lauraceae:
- Spicebush, *Benzoin aestivale.*
- *Sassafras, *Sassafras variifolium.*

Brassicaceae ("Cruciferae"):
- Cabbage, *Brassica oleracea capitata.*
- Rutabaga, *Brassica campestris.*
- White mustard, *Brassica alba.*

Saxifragaceae:
- Gooseberry, *Ribes grossularia.*
- ———, *Ribes oxyacanthoides.*
- Red currant, *Ribes rubrum.*
- Mockorange, *Philadelphus coronarius.*

Hamamelidaceae:
- Sweetgum, *Liquidambar styraciflua.*

Platanaceae:
- American planetree, *Platanus occidentalis.*

Rosaceae:
- Flowering quince, *Chaenomeles lagenaria.*
- *Quince, *Cydonia oblonga.*
- Hawthorn, *Crataegus* sp.
- Chiloe strawberry, *Fragaria chiloensis.*
- *Apple, *Malus sylvestris.*
- American mountain-ash, *Sorbus americana.*
- *Plum, *Prunus domestica.*
- Black cherry, *Prunus serotina.*
- *Cherry, *Prunus* sp.
- Oriental cherry, *Prunus serrulata.*
- *Peach, *Amygdalus persica.*
- *Rose, *Rosa* sp.
- *Highbush blackberry, *Rubus argutus,*

Rosaceae—Continued.
- Sand blackberry, *Rubus cuneifolius.*
- *Blackcap, *Rubus occidentalis.*
- Vanhoutte spirea, *Spiraea vanhouttei.*
- Hardhack, *Spiraea tomentosa.*
- *Kerria, *Kerria japonica.*

Fabaceae ("Leguminosae")
- *Soybean, *Soja max.*
- Alfalfa, *Medicago sativa.*
- Hoary tickclover, *Meibomia canescens.*
- Lima bean, *Phaseolus lunatus marcocarpus.*
- Common bean, *Phaseolus vulgaris.*
- Common locust, *Robinia pseudoacacia.*
- Chinese wisteria, *Kraunhia sinensis.*
- Alsike clover, *Trifolium hybridum.*
- Red clover, *Trifolium pratense.*

Geraniaceae:
- Geranium, *Pelargonium domesticum.*

Oxalidaceae:
- Common yellow oxalis, *Oxalis stricta.*

Simarubaceae:
- Tree-of-heaven, *Ailanthus altissima.*

Euphorbiaceae:
- Mercuryweed, *Acalypha virginica.*
- Castor-bean, *Ricinus communis.*

Anacardiaceae:
- Staghorn sumac, *Rhus hirta.*
- Poison-ivy, *Rhus radicans.*

Aquifoliaceae:
- Winterberry, *Ilex verticillata.*

Aceraceae:
- Silver maple, *Acer saccharinum.*
- Japanese maple, *Acer palmatum.*
- Norway maple, *Acer platanoides.*
- Sycamore maple, *Acer pseudoplatanus.*
- Sugar maple, *Acer saccharum.*
- Red maple, *Acer rubrum.*
- Boxelder, *Acer negundo.*

Hippocastanaceae:
- *Horse-chestnut, *Aesculus hippocastanum.*

Sapindaceae:
- Bladdernut, *Staphylea trifolia.*

Balsaminaceae:
- Spotted snapweed, *Impatiens biflora.*

Vitaceae:
- *Summer grape, *Vitis aestivalis.*
- *Fox grape, *Vitis labrusca.*
- *Virginia creeper, *Parthenocissus quinquefolia.*

*Tiliaceae:
- American linden, *Tilia americana.*
- Littleleaf European linden, *Tilia cordata,*

Malvaceae:
- *Marshmallow, *Althaea officinalis.*
- *Hollyhock, *Althaea rosea.*
- Okra, *Hibiscus esculentus.*
- Common rosemallow, *Hibiscus moscheutos.*

Violaceae:
- Violet, *Viola* sp.

Onagraceae:
- *Evening-primrose, *Oenothera biennis.*

Apiaceae ("Umbelliferae"):
- Carrot, *Daucus carota.*

Ericaceae:
- Swamp azalea, *Azalea viscosa.*
- Catawba rhododendron, *Rhododendron catawbiense.*
- Summersweet, *Clethra alnifolia.*

Oleaceae:
- Green ash, *Fraxinus lanceolata.*
- White ash, *Fraxinus americana.*
- Weeping forsythia, *Forsythia suspensa.*

Apocynaceae:
- Spreading dogbane, *Apocynum androsaemifolium.*

Asclepiadaceae:
- Purple milkweed, *Asclepias purpurascens.*
- ———, *Asclepias* sp.

Convolvulaceae:
- Sweet potato, *Ipomoea batatas.*

Polemoniaceae:
- Phlox, *Phlox* sp.

Verbenaceae:
- Blue vervain, *Verbena hastata.*
- White vervain, *Verbena urticaefolia.*

Menthaceae ("Labiatae"):
- Motherwort, *Leonurus cardiaca.*
- Peppermint, *Mentha piperita.*
- Oswego beebalm, *Monarda didyma.*
- Wildbergamot, *Monarda fistulosa.*
- Catnip, *Nepeta cataria.*
- Scarlet sage, *Salvia splendens.*
- American germander, *Teucrium canadense.*

Solanaceae:
- Eggplant, *Solanum melongena.*
- Potato, *Solanum tuberosum.*
- Common matrimony-vine, *Lycium halimifolium.*

Scrophulariaceae:
- Common toadflax, *Linaria vulgaris.*

Bignoniaceae:
- Trumpetcreeper, *Tecoma* sp.

Plantaginaceae:
- Common plantain, *Plantago major.*
- Plantain, *Plantago lanceolata.*

Rubiaceae:
- *Buttonbush, *Cephalanthus occidentalis.*
- Bedstraw, *Galium pilosum.*
- Bedstraw, *Galium claytoni.*

Caprifoliaceae:
- *American elder, *Sambucus canadensis.*
- *European cranberrybush, *Viburnum opulus.*
- Honeysuckle, *Lonicera* sp.

Cucurbitaceae:
- Watermelon, *Citrullus vulgaris.*
- Cantaloupe, *Cucumis melo.*

Lobeliaceae:
- Cardinalflower, *Lobelia cardinalis.*

Asteraceae:
- Yarrow, *Achillea millefolium.*
- Sky-drop aster, *Aster patens.*
- Aster, *Aster vimineus.*
- Wave aster, *Aster undulatus.*
- Oxeye daisy, *Chrysanthemum leucanthemum.*
- Groundselbush, *Baccharis halimifolia.*
- Dahlia, *Dahlia rosea.*
- Dahlia, *Dahlia variabilis.*
- Fleabane, *Erigeron annuus.*
- Horseweed, *Erigeron canadensis.*
- Fleabane. *Erigeron ramosus.*
- White thoroughwort, *Eupatorium album.*
- Rough Joe-pye-weed, *Eupatorium maculatum.*
- Joe-pye-weed, *Eupatorium purpureum.*
- ———, *Galinsoga parviflora.*
- Sunflower, *Helianthus annuus.*
- Goldenrod, *Solidago* sp.
- Ragweed, *Ambrosia elatior.*
- Great ragweed, *Ambrosia trifida.*
- Ironweed, *Vernonia noveboracensis.*
- Aztec marigold, *Tagetes erecta.*
- French marigold, *Tagetes patula.*

INJURIES TO VARIOUS ECONOMIC PLANTS

By the Adults

During the period of 1921 to 1924 studies were conducted relative to the injury caused by the beetles to leaves and fruit on various orchard trees; these investigations included a study of the extent and diversity of the feeding, a comparison of the flora, and observations of the amount of feeding on various definite plots.

The extent of the injury to leaves and fruit was observed by inspecting each tree and shrub: by count, measurement, and esti-

mation, the actual loss in food-manufacturing surface occasioned by beetle injury to the foliage was determined. The amount of injury to the fruit was obtained by actual count of the peaches, apples, and plums which had been damaged by the beetles.

During 1921 about 3,200 trees and in 1922 a total of 69,423 trees were inspected in this manner. These included the fruit trees in 145 orchards in the heavily infested area, as well as trees and shrubs, representing 60 ornamental varieties, found on lawns within the area. Tables 1 and 2 present some of the results of these inspections.

TABLE 1.—*Results of survey of injury to orchards in 1921 caused by the Japanese beetle*

Species	Number of trees	Highest percentage of injury	Average percentage of injury	Species	Number of trees	Highest percentage of injury	Average percentage of injury
Apple foliage	106	80	30	Peach fruit	140	[1] 30	13
Do	352	20	10	Sour cherry foliage	30	95	50
Peach foliage	468	95	50	Do	500	70	35
Do	717	75	10	Sweet cherry foliage	13	90	85
Do	78	95	75	Grape foliage	731	60	20
Do	140	95	50				

[1] Eight trees.

TABLE 2.—*Results of survey of injury caused by the Japanese beetle to fruit trees in 1922*

Percentage of foliage destroyed by beetles	Number of trees	Percentage of foliage destroyed by beetles	Number of trees
10	24, 674	90	341
20	2, 597	100	85
30	3, 773		
40	1, 453	Total	36, 092
50	1, 180	Uninjured	33, 186
60	754	Died	145
70	628		
80	607	Total number examined	69, 423

Pears were not injured to any extent in 1921 or 1922, although in 1921 several trees of the Japanese sand pear located near Moorestown, N. J., lost between 40 and 50 per cent of their foliage through destruction by the beetles. In 1923 several trees of Le Conte were severely attacked. During 1922 quince and small fruit suffered less than 25 per cent injury to foliage. Apples which ripened late in the season were not so severely injured as those which ripened early. Highly colored peaches, particularly the early ripening varieties, such as Early Wheeler (*Red Bird*), Greensboro, and Rochester, suffered the most severe injury to both foliage and fruit.

In the seasons of 1922 and 1923 the heaviest feeding by the beetles occurred between June 26 and July 6. During this time the orchards suffered the greatest injury. The maximum numbers of beetles were present in the orchards between Riverton and Moorestown, N. J., about July 1. The amount of daily injury began to lessen by July 18; by July 25 a marked decrease in injury was observed. Between

July 18 and 25 a diminution in the numbers of beetles present was also noted.

In 1923 examination was made of 66 apple trees, 39 of which were sprayed with arsenate of lead as a protection against the beetle, and 27 were left unsprayed. The average injury to the sprayed trees was 20 per cent loss of foliage, whereas the average foliage loss on those which were unsprayed was 82 per cent. These figures are representative of the large accumulation of data and show the protection afforded certain varieties of fruit through the application of arsenical sprays.

During the season of 1923 and in the early part of the season of 1924 the beetles caused greater damage than in 1922. The area where heavy feeding occurred has increased each year, and in many localities if sprays are not promptly and thoroughly applied to fruit trees defoliation is almost certain to result. The damage to the fruit itself has been increasing. One grower in 1923 lost over $1,200 on his early peaches. Records which are by no means complete for the area as a whole show that in 1923 in the heavily infested area in New Jersey the loss due to injury to early apples was about 15 per cent of the crop. Data for 1924 are not as yet complete, but the fruit injury will be greater than in 1923. The percentage of the crop of early-ripening varieties of peaches lost through injury by the beetles has exceeded the loss in the case of apples. The most serious fruit injury has been done to early ripening varieties of apples, such as Williams, Star, Yellow Transparent, and Astrachan, and to the varieties of peach such as Carman, Early Wheeler (*Red Bird*), Greensboro, and Rochester.

By the Larvæ

Owing to the fact that the larvæ of the Japanese beetle occur in the soil and feed on the roots of living plants, it is difficult to estimate the resulting damage to the several crops and plants of economic importance which they may attack.

Severe injuries have been suffered by various grasses which occur in pastures and lawns and on golf courses. Injuries have been also noted on such plants as beans and other vegetable crops and on certain ornamental plants growing in areas where the infestation of the larvæ was heavy.

During the season of 1922 severe injuries were noted on strawberries, caused by the larvæ feeding on the roots. In one instance a field of strawberries which had been set for three years was practically destroyed as a result of the root-feeding habits of the larvæ. On the same farm a field of strawberries was set in the spring of 1922, in some rows of which as high as 80 per cent of the plants were destroyed by the larvæ. If the concentration of the beetles continues to increase, serious damage will be done to hay, field pastures, and lawns. When the infestation of larvæ is more than 200 to the square yard, injuries may be noted to the grass, particularly if a period of dry weather occurs during the latter part of May or June. In the falls of 1922 and 1923 the fairways in several of the local golf courses suffered severe injury as a result of the feeding of the larvæ.

DESCRIPTION AND BIOLOGICAL FEATURES

THE EGG

The eggs of the Japanese beetle are elliptical bodies (fig. 2), approximately one-sixteenth inch in diameter, which vary from a translucent white to a creamy color. The surface appears finely punctate when observed under high magnification, the tiny punctures being somewhat hexagonal in shape. There is considerable variation in the shape and size of the eggs, particularly during the first four or five days after they have been deposited. It has been observed that a few of the eggs are almost perfect spheroids; others show considerable difference between the two diameters. The eggs do not increase in size until six or seven days after they have been laid. At this time they begin to enlarge and become more spherical in shape. By the seventh day the embryo larva can be seen through the shell, and by the eighth or ninth day the eggs are nearly twice as large as they were when deposited by the female beetle. When eggs were placed in moist soil and kept at temperatures ranging between 75° and 80° F., the average time required to hatch was 14 days, the minimum being 9, and the maximum 27 days. One hundred and thirteen eggs were kept in soil at a constant temperature of 68° F.; in this case the average length of time required for the eggs to hatch was 21 days, the extremes being a minimum of 13 and a maximum of 28 days. It was noted that in every large series of eggs the hatch was never less than 88 per cent where the eggs were kept in moist soil at temperatures above 55° F. and below 98° F.

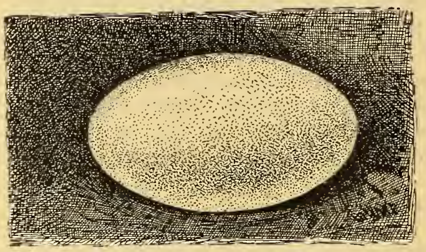

FIG. 2.—Egg of the Japanese beetle. Highly magnified

There is considerable variation in the length of the egg period, depending upon the kind of soil and the temperature and moisture conditions under which eggs may occur in the field. Many are laid late in the season and, owing to low soil temperatures, probably fail to hatch.

THE LARVA

Upon emerging from the egg the young larva or grub is about one-sixteenth inch long, and feeds on soil, decayed vegetable matter, and, to a less extent, on tender fibrous roots. Before the larva molts its food consists almost entirely of partially decomposed plants. Its first stage is usually completed in from 7 to 10 days. During the spring of 1921 three first-instar larvæ were collected in the field, and in the spring of 1922 one. Whether these individuals passed the winter as larvæ or as eggs is still a question; the evidence obtained, however, indicates that they passed the winter as eggs, since the last record of the finding of first-instar larvæ in the field in 1921 was dated November 2, whereas eggs were found as late as December.

The second molt usually occurs on an average 12 to 20 days after the first, although from 4 to 6 per cent of the larvæ found in the

spring have not passed the second molt. Second-stage grubs are usually about one-half inch long. There is a great variation in the length of this period of development, depending on the time when the larva is hatched, the food supply, temperature, moisture conditions, and probably other influencing factors not as yet determined. It is noticeable that in different fields the rate of development varies considerably, and the greatest differences in this rate in the case of various individuals are to be noted during the period of the second instar.

A majority of the larvæ become full grown and reach a length of about 1 inch by the third or fourth week in September, and it is at this time that the heaviest feeding on plant roots is done. The

FIG. 3.—Full-grown or third-stage larva of the Japanese beetle. Greatly enlarged

winter is usually passed in this stage. (See Pl. II and fig. 3.) Upon becoming full grown in the spring, the larva prepares an earthen cell, in which it pupates. The cell is made by the movements of the larva and the soil is gradually packed until a smooth cavity is formed of sufficient size to provide for the activity and the movements necessary for pupation and emergence. The larva then ejects the accumulated excrement, and the body gradually assumes the prepupa form. This is a semi-inactive condition between the active larva and the quiescent pupal stage. It remains in this prepupal condition for a period of 3 to 17 days, or an average of about 11 days.

THE PUPA

The movements of the developing pupa within the larval skin cause the latter to split and the pure white pupa is exposed. Later the pupa gradually assumes a rusty brown or tan color. After re-

maining as a pupa for from 8 to 20 days it transforms and splits the pupal shell, and gradually withdrawing its body and appendages issues an adult beetle. The adult is soft and delicate at first and usually remains in the earthen cell for several days before emerging from the ground. The pupa averages 14 millimeters (about 0.55 inch) in length and 7 millimeters (about 0.28 inch) in width. A few days before the adult issues the pupa assumes the metallic green of the beetle. The form of the pupa and the serrate abdominal segments are shown in Plate II and in Figure 4.

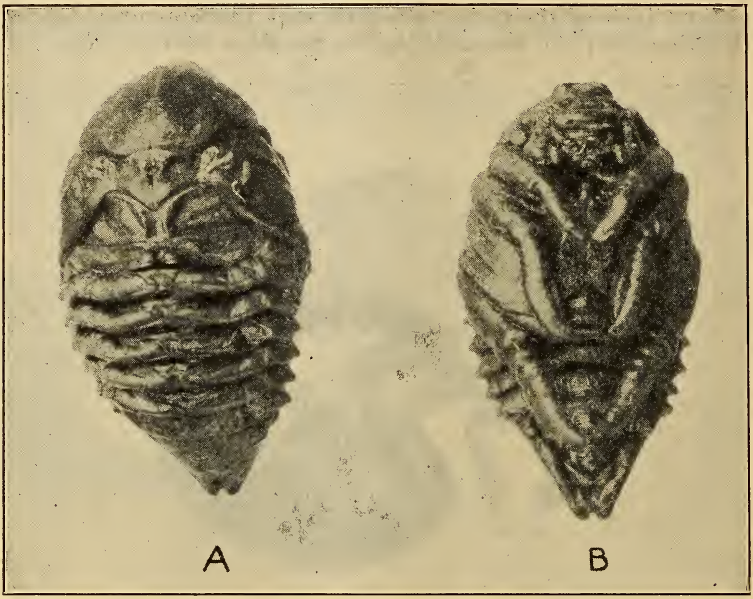

FIG. 4.—A, Dorsal, and B, ventral, views of pupa of the Japanese beetle. Greatly enlarged

THE ADULT

The adult Japanese beetle is a beautiful and brightly colored insect, varying in length from five-sixteenths to seven-sixteenths inch and in width from three-sixteenths to nine-thirty-seconds inch. It is broadly oval in shape, moderately convex, and shining. The upper surface is somewhat flattened, without pubescence, hairs, or scales. The color is bright metallic green, except the greater part of the wing covers, which are coppery brown. The elytra do not cover the abdomen, but expose a row of five lateral and two posterior marginal spots composed of white hairs. The under surface of the body is clothed with short, grayish hairs. The head is thickly and coarsely punctured; the striæ of the elytra are double punctured, the second stria is imperfect, terminating considerably below the apex of the elytron. The legs are of a dark, metallic, coppery green color, varying in tint in different positions. The sexes are most easily distin-

guished by slight differences in the form of the tibia and tarsus (fig. 5). Plate II, in colors, illustrates the form and color of the adult Japanese beetle.

THE HABITS OF THE INSECT

EMERGENCE OF ADULTS

After transforming to the adult the beetle remains in the pupal cell from 2 to 14 days before coming out of the ground. There is considerable variation in the size of the adult Japanese beetles. As a rule the females are larger than the males. From the writers' experiments they have found that the size of the larva does not necessarily indicate the size of the adult which may develop from it. The size of the larva, however, is dependent on its food supply. After emerging from the ground the beetles usually climb on various low-growing plants, and if the weather is clear remain for a few hours without feeding until they are thoroughly hardened. In many cases, however, they have been observed copulating, and in some cases the females have returned to the soil and deposited fertile eggs before any food was taken.

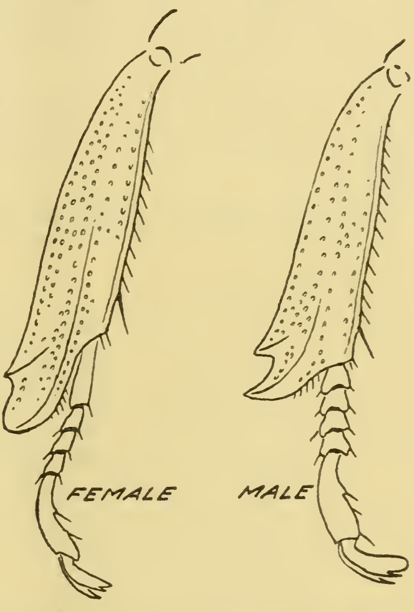

FIG. 5.—Fore-tibiæ and tarsi of the Japanese beetle, greatly enlarged, showing difference in structure between male and female beetles. It is by the character of the spur on the outer end of the tibia that the sexes are most easily distinguished

LENGTH OF LIFE OF ADULTS

Experiments conducted relative to the length of life of the beetles indicate that the male beetles collected upon emergence in the field and brought to the laboratory lived for an average of 46 days. Female beetles collected under the same conditions lived for 44 days. It was found that in the case of beetles which were reared from larvæ kept in cages in the insectary the males lived for an average of 34.25 days and the females for 37.94 days. In all cases the beetles were supplied daily with food in the form of fresh sassafras leaves. To learn how long the beetles would live without food, 100 females and 100 males reared from larvæ in cages were kept continuously without food until they died. The average age for male beetles was 7.25 days; for females, 8.50 days. Copulation occurred normally and the females laid the usual number of fertile eggs.

EGG-LAYING HABITS

It was found that in a majority of cases the females enter the soil late in the afternoon and deposit one to three or four eggs during the

night. Some beetles have been found to remain three or four days in the soil. In many cases, however, eggs are laid every third or fourth night, and the egg-laying period extends over three or four weeks. During the morning the beetles concentrate on low-growing plants, such as smartweed and beans. As the heat increases during the day they become more active and disperse to the taller plants until early in the afternoon, when they are abundant on the tallest elms, oaks, and maples. After 3 p. m. their flight is toward the ground and the lower-growing plants. Data collected show that one sex is as likely as the other to begin a new infestation, provided there are equal numbers of both sexes flying at the time. Hourly and half-hourly collections from several food plants showed that the proportion of females to males was highest between 12 o'clock noon and 2 p. m. and was lowest between 6 p. m. and 6 a. m. The most marked difference in the proportion of the sexes was noted on the taller plants at the different times, whereas on the low-growing species such as smartweed the least difference was observed. The writers' observation indicates that a proportion of the females leaving the taller trees may not enter the soil, but remain on low weeds during the night.

There is a general increase in the activity of the beetles during the day until 2 or 3 p. m.; after this time their activity decreases until dark when flight ceases.

There is a distinct movement of the males toward those plants on which the females are feeding. On clear days, between 8 and 9 a. m., numerous males can be observed flying low over the ground in search of emerging females. During the early part of the day this tends to concentrate the beetles on low-growing plants, such as smartweed, beans, and various weeds. In 1922 this habit was particularly noticeable on the golf course at Riverton. On clear days the beetles' flight commenced between the hours of 8 and 8.30 a. m., and the first beetles found on the wing were invariably males. As the females would issue from the ground the males would alight and attempt copulation before the females had opportunity to take flight. This resulted in a large number of males alighting on and near the female, and in their attempts at copulation the congregated beetles resembled balls. From one of these masses with only 1 female present 198 males have been collected. It was observed that in alighting the males always approached the female against the wind, apparently being attracted by the odor, and when they alighted on the ground it was usually from 4 to 6 inches on the leeward side of the female, which they approached by crawling along the ground. As the males drew in rapidly this resulted in a trail of male beetles several inches long extending from the ball which was forming about the female. As the wind would shift slightly the direction of the trail of males would change within two or three minutes, so that the trail of beetles was always directly opposite to the direction in which the wind was blowing. Apparently copulation rarely took place when so many males were present. In only one instance upon examination of several hundred of these balls was the female found to be in the act of copulation. The habit of balling usually ceases about midday, not to recur again until the following morning. In an area of 25 square yards on a golf course 78 balls of the beetles were observed at one time, each ball being composed of a single female and from 25 to 200 male beetles.

FOOD HABITS OF THE LARVÆ (9)

The feeding habits of the larvæ have been observed many times, both in the laboratory and in the field, and have been found to differ somewhat from those of certain of our native species. The larva forms a cell in the soil slightly larger than its body and feeds on the fine rootlets at the top and bottom of the cell. (See Pl. II.) The grubs usually follow the course of the rootlets until these are consumed before attacking others. It is this habit of feeding which has prevented injury to grass from being extremely serious, since it is only in areas of heavy infestation that many plants have been found of which all the roots have been destroyed. It also follows that in areas which suffer from drought the injury has been most noticeable and severe. The general movements of the larvæ in the soil are vertical, whereas the larvæ of the native Cyclocephala (*Ochrosidea immaculata* Oliv.) and Anomala (*Pachystethus lucicola* Fabr.), which are abundant in this region, usually feed and move in a direction parallel with the surface of the ground. During the seasons when the Japanese-beetle larvæ are feeding they occur in the soil at depths varying between one-half inch and 3 inches. The depth at which the larvæ are found is more uniform for a short time before they descend on the approach of cold weather in the fall, and again during the period preceding pupation.

The larvæ are positively thigmotropic and are attracted to living roots, and if these are not available, to stones or sticks or to the bottom and sides of the breeding cages. They have been found abundant beneath stones in the field; for a distance of 2 or 3 feet from these stones no larvæ could be found, although at a distance of 5 or 6 feet from the stones there would be 20 to 25 larvæ to the square yard. In a young peach orchard which was cultivated the previous season and allowed to remain fallow over the winter, there were numerous chickweed plants growing in the spring of 1921. In the spaces between these plants the ground was bare. Fifty plots, each 3 feet square in area, where no vegetation occurred, were examined and no larvæ were found. On the removal of 50 chickweed plants an average of seven larvæ were found at the roots of each plant.

Dissections were made of a large series of larvæ collected in grass sod, and the contents of the fore part of the alimentary canal were carefully removed. It was found that the material eaten by the insects was composed of small soil particles, fresh plant tissue, and small pieces of plants which were partially decomposed. Analysis of the material eaten by 25 larvæ showed it to be composed as follows:

	Grams
Total weight of food collected	21.4134
Dry weight of food collected	15.4769
Ash remaining after ignition	5.0556
Loss from ignition	10.4213

These figures indicate that organic material constitutes about 67.33 per cent by weight of the total material consumed by the larvæ.

On examination of the material contained in the fore part of the alimentary canal, the soil particles and pieces of plant tissues were

found to be relatively uniform in size. The greatest variation occurred in those tissues which were partially decomposed.

Microscopic examination was made of the material contained in the fore part of the alimentary canal, and the fresh plant tissues were separated from those which were partially decomposed. Counts were made of the number of pieces of the various materials, and the following tabulated statement indicates the approximate number and character of the particles of material found:

Total number of pieces of fresh plant tissue, 1,375, or 64.3 per cent.
Total number of pieces of decayed plant tissue, 419, or 19.6 per cent.
Total number of pieces of mineral matter, 344, or 16.1 per cent.

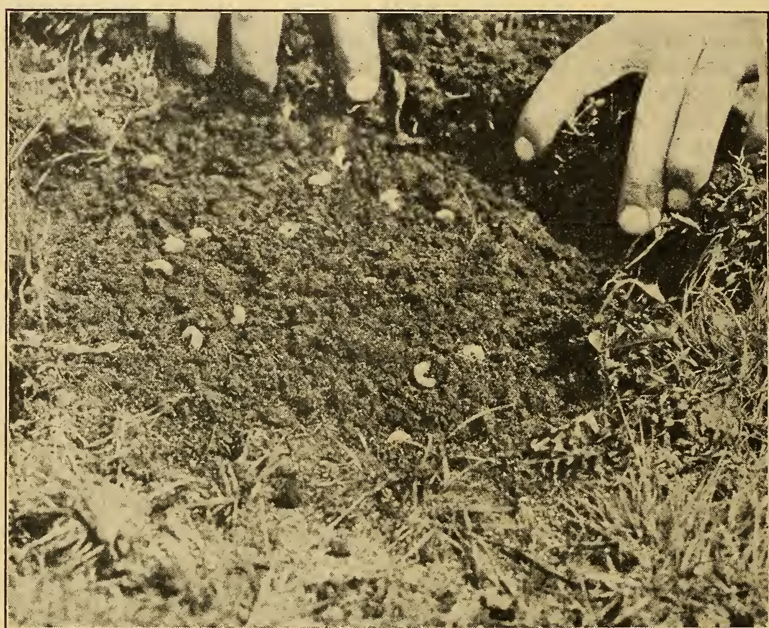

FIG. 6.—Dead sod turned back to show abundance of grubs of the Japanese beetle and the depth to which they feed

From these figures it will be seen that from 25 larvæ approximately 84 per cent by volume of the material eaten was vegetable matter; 64.3 per cent of the total amount of material consumed was from the roots of living plants.

A series of experiments was conducted to determine the mortality of the larvæ when reared in soils containing varying amounts of organic material. From the data obtained, it is believed that though the larvæ may survive in soil a certain length of time without living roots upon which to feed, the presence of the roots is extremely important for their development. This belief has also been borne out by results in the rearing cages, where entire series have died for no apparent reason other than starvation when sod was not added to the soil.

During April and May, 1921, larvæ were observed actively feeding on the roots of rye, clover, and several of the pasture grasses. Further observations made in fields of rye disclosed the fact that in nearly all cases the larvæ were congregated about the roots of the rye stools. Larvæ have also been found feeding on the large taproots of clover, some of which were nearly eaten through between 1 and 2 inches below the crown. The larvæ do not confine their attacks to grasses and legumes, since records have been obtained of their feeding on the roots of such plants as iris, peony, gladiolus, arborvitæ, small conifers, and other ornamental plants and shrubs, and also on the roots of corn, beans, tomatoes, and other vegetable crops.

The first injuries to grass sod which were noted were found in a pasture in which the larvæ numbered between 150 and 200 to the

Fig. 7.—Lawns along river front at Riverton, N. J. The light areas are dead sod killed by the feeding of grubs of the Japanese beetle

square yard. Areas were injured to such an extent that the sod could be easily rolled up with the fingers. Many of the plants the roots of which were not entirely eaten off by the grubs were killed by the hot, dry weather prevailing later in the season. Many weeds and coarse-rooted grasses do not show any appreciable effects from the feeding of the larvæ, whereas the finer-rooted species, such as bluegrass and redtop, are killed. For this reason it is probable that the most important injury by the larvæ will not usually result in the destruction of the sod, but rather in the killing out of the more desirable species of grasses for pasture or hay purposes, and their being replaced by less desirable species.

Golf courses offer particularly favorable situations for the development of the larvæ. The Country Club course at Riverton, N. J., has

for the past three years been generally infested with the larvæ. On the fairways and in the rough the infestations were variable. On an average of a number of diggings less than 50 larvæ to each square yard were found in the spring of 1921. During 1922 several of the fairways at the Riverton course had infestations of the larvæ varying between 300 and 800 to the square yard, and the sod was so severely injured that in some cases the fairways had to be torn up and reseeded in the fall. In 1923 the infestation in the putting greens was considerably heavier, and in order to save them treatments were made to destroy the larvæ. Aside from the direct injury to the grass roots, the playing surface was rendered soft and spongy by the burrowing of the larvæ in the soil. It was noticeable that the most severe injury to the grass occurred on the higher portions of the greens and especially about the margins. These would probably be the places which would receive the least water when the greens were sprinkled. Much of the feeding on the greens was done just below the surface of the ground, the larvæ being in most cases between one-half and three-fourths inch beneath.

Figures 6 and 7 illustrate the abundance of the larvæ under sod killed by them and the extensive damage to sod ground which may result from their activity.

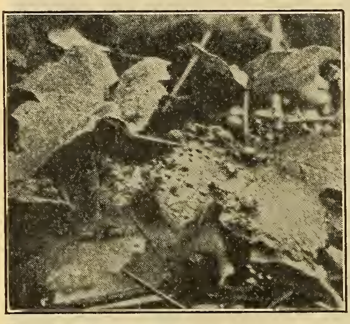

Fig. 8.—Japanese beetles commencing to feed on a grape leaf

Fig. 9.—Beetles clustered and feeding on blades of coarse grass

FOOD HABITS OF THE ADULT (*10*)

The Japanese beetle is most conspicuous and injurious in the adult stage by reason of its active habits and the injuries it causes to foliage and fruit (figs. 8 to 14). The injury to foliage is most conspicuous and characteristic, being comparable with the eating done by native leaf-chafers. Small plants may be defoliated; on trees the leaves are usually skeletonized, and when severely eaten they turn brown and drop, thus producing the same effect as defoliation. Since the beetles prefer to feed on foliage exposed to the direct rays of the sun, it is not usual for them to defoliate entirely the larger shade and timber trees. Usually they commence to feed on the upper and outer foliage and work downward; by the time one-half or two-thirds of the foliage on the tree in question has been consumed, the beetles will leave and congregate on other plants. Such injury does not immediately produce a visible detrimental effect on the trees. If such feeding is continued year after year under the present numerical concentration of the beetles, however,

it will result in the destruction of many fine and valuable ornamental trees.

Fruits which ripen early in the season are most subject to the attacks of the beetles. This injury has been noted as being especially

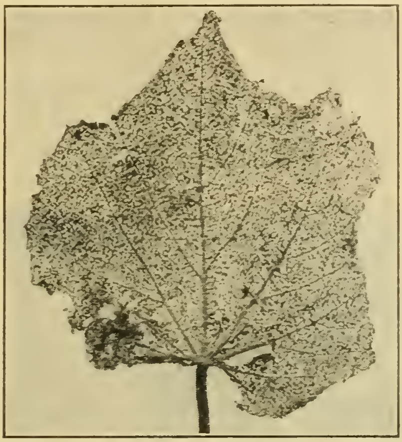

Fig. 10.—Grape leaf destroyed by feeding of the Japanese beetle. The soft tissues have all been eaten and only the network of veins remains

Fig. 11.—Linden defoliated by the Japanese beetle

Fig. 12.—Twig from an elm showing characteristic injury by the Japanese beetle

Fig. 13.—An elm tree near Moorestown, N. J., showing how the outer portions have been defoliated by feeding of the Japanese beetle

severe in apple orchards which were poorly cared for and in which, in consequence of the injuries of the codling-moth larvæ and other insects, a large part of the fruit ripened prematurely, and in peach orchards where brown-rot affected much of the fruit. The cull fruit

is undoubtedly the first to be eaten by the Japanese beetle. The beetles do not stop with their feeding on such fruit, but later attack sound, ripening fruit. By actual count on certain peach trees of the variety Rochester, 87 per cent of the fruit was destroyed by the Japanese beetle. As many as 5 bushels of fruit injured by the beetles have been harvested from a single apple tree of the Yellow Transparent variety. First injury to apple fruit was noted in 1919 and injury to peaches was first seen in 1920.

Injury to the developing ears of corn has been noted since 1919 (figs. 15 and 16). The seriousness of this injury, involving as it does one of the great staple crops of the United States, can not be overlooked. The beetles are extremely fond of the green corn

Fig. 14.—A smartweed plant upon which the Japanese beetles are feeding

silk and the developing ear, and cluster at the tip, frequently by dozens, cutting off the green silk close to the husk and feeding on the green developing kernels at the tip of the ear. Frequently ears have been noted on which the grains and husk were eaten for more than half the length of the cob. When the beetles are abundant it is not unusual to find fields of either sweet or field varieties of corn in which from 95 to 100 per cent of the ears are injured by the beetles; from 10 to 15 per cent of these are rendered unfit for market purposes. The injury to the ears is in most respects more serious than that caused by the earworm (*Heliothis obsoleta* Fab.). It is possible that the cutting off of the green silk from the ears causes an imperfect pollination of the corn. This type of injury also occurs in red clover. It has been noted that the beetles are

attracted to the blossoms of red clover, and feed largely on the floral parts. Observations indicate that by feeding in this manner the beetles are capable of preventing fertilization of the blossoms and thus hinder the subsequent production of clover seed.

It should be noted that certain crops little or not at all molested in 1919 were vigorously attacked in later years. Peach fruit and the foliage of cultivated sour cherry were unattacked until the season of 1920. These instances show the serious possibilities of injury by this beetle and suggest that they are likely to increase as the territory infested becomes larger. The degree of infestation of the various food plants is not constant. At times a plant or group of plants may have numerous beetles on them and later observations show that the insects have left them for other food plants. Instances have been noted on peach, smartweed, sassafras, and apple where the plants were heavily infested for awhile and later had very few beetles feeding on them. In some cases the plants in question were not reinfested during the season.

Fig. 15.—Japanese beetles feeding on staminate flowers and blades of corn

The Japanese beetle may properly be termed "polyphagous" in its food habits, having been recorded as attacking more than 200 species of plants. In the past certain species more than others have been injured by the beetles. As the beetles do not feed consistently on any one type of plant, a general statement that one particular species is preferred can not be made. Almost no plants, excepting certain conifers, are exempt from attack between June and November when the beetles are present. At times they will be found abundantly on low-growing plants, such as white clover (*Trifolium repens*), violet (*Viola* sp.), or galinsoga (*Galinsoga* sp.), or they may feed on the taller types of shade trees. It was at first believed that the succulency of the leaves influenced the insects to a great extent in the selection of their food plants. Later observations indicate that this in itself is not the deter-

mining factor in the apparent preference shown for certain species. During the period between June 18 and 20, 1923, a 2-year-old peach orchard became infested, and the foliage on the mature wood was eaten first. About 20 per cent of the leaves were destroyed by the feeding of the insects. Between the 8th and 12th of the following month, when the abundance of the beetles was at its height, they left these peach trees for other food plants. These particular peach trees were not reinfested during the season, although a sour-cherry orchard adjacent to the peaches was more or less heavily infested from June to October. A bearing peach orchard, about 100 yards distant from the young orchard mentioned, suffered a similar temporary infestation with the exception that the beetles did not leave until August.

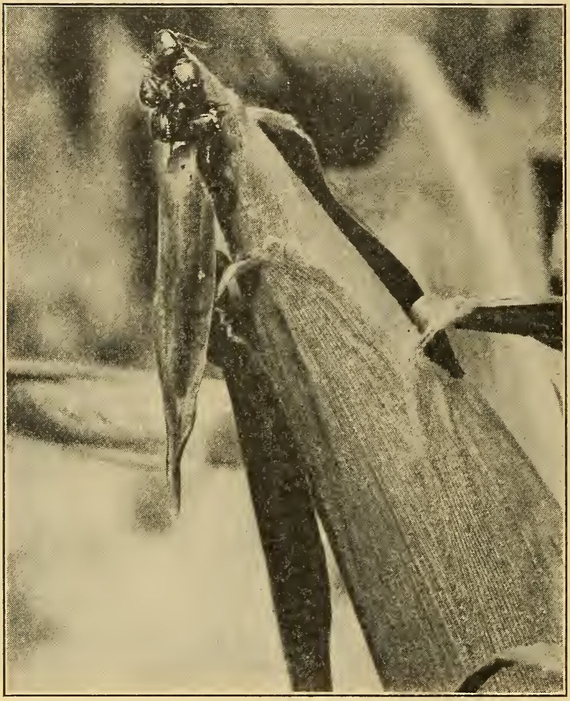

Fig. 16.—Japanese beetles feeding on silk at tip of an ear of field corn

A large patch of smartweed, near the center of the area where the insect is most abundant, became infested June 17, 1921. By July 1 hundreds of beetles were present on the plants each day. On July 10 it was noted that the beetles were less abundant, although there was still plenty of foliage upon which they could feed. By July 12 only six beetles were on this particular patch of smartweed, five males and one female. Thereafter the infestation noted on these plants was as follows: July 13, 2 males; July 14, 7 males; July 15, none; July 16, none; July 19 at 9 a. m. 3 males, at 3.30 p. m. 7 males; July 20 at 9.30 a. m. 3 females and 10 males, at 11.30 a. m. 12 females and 22 males, and by 2 p. m. the plants were heavily infested; 120 beetles were collected at random from these plants, and of these 52 were females and 68 males. This patch remained infested until after September 15, 1921. Similar instances have been noted on sassafras and Yellow Transparent apples.

The beetles are strongly attracted to ripening fruit, and early apples and peaches may suffer severe injury from the depredations of the insects (see figs. 17 to 23). So numerous do the beetles become at times that individual fruits, especially where they have prema-

turely ripened, will be completely covered by a swarming mass of the insects. As many as 278 beetles have been removed from a single apple. It has been noted that the foliage of those varieties which ripen early in the season is more severely injured than is that of the so-called late varieties. It is possible that this may in a measure be caused by some attraction of color or odor of ripening fruit rather than by a preference for the foliage of the early varieties. No apples have been observed to be severely attacked early in the season, and it is only after some of the fruit has partially ripened, either prematurely through disease or otherwise, that the heavy infestations occur on apples. Peaches affected with brown-rot caused by *Sclerotinia fructigena* (Pers.) Schr. are particularly attractive to the beetles, and these insects may yet cause serious losses by carrying this fungus from diseased to sound fruit.

Fig. 17.—An apple upon which Japanese beetles are feeding

Fig. 18.—Injury to foliage of apple and Japanese beetles clustered on the fruit

Throughout the season when the beetles are present they may be found at any time on a large number of plant species. In general, however, during the past three years beetles have shown a tendency to be more abundant on weeds, sassafras, elder, sweet cherries, and grapes during the early part of the season. By midsummer fruit and shade trees were more heavily infested, and during August and September heavy infestations were confined to corn, beans, clover, and various plants in bloom at that time. During the season of 1922 the infestation was much heavier on fruit than during the previous year. This is probably accounted for by the fact that there was a very light crop of fruit in the season of 1921. During the seasons of 1922 and 1923 there were a marked increase in the fruit crop and a heavier infestation of beetles. The developing ears of corn were particularly attractive to the beetles, and as many as 27 individuals have been taken from a single ear.

The Japanese beetles are positively phototropic, and most of their feeding is done on plants which are exposed to the direct rays of the

sun. As a result, the first injury to the foliage of various trees occurs on the outer portions of the top and side branches. Early in the season the beetles rarely feed on the peach leaves borne on new wood. As the season progresses, however, they feed more or less generally on the mature foliage. It is of interest to note that on the majority of their food plants the beetles feed on the upper surfaces of the leaves, while in the case of peaches if there were any preference shown for one side of the leaf or the other the preference would probably be for the under side.

The beetles mate and feed more or less intermittently, and there is a considerable movement of the beetles from plant to plant during

Fig. 19.—Apple injured by the Japanese beetle

the day. A female beetle on a plant will quickly attract many males and, owing to the gregarious habits of this species, other females as well. The males become active and are flying in the morning before the majority of the females have emerged from the soil. During this period the male beetles feed erratically and for short periods on a large variety of plants.

Later in the day, as the number of females in flight increases, the males usually select a plant on which one or more beetles are present. Between the 10th and 20th of July observations were made on five 2-year-old peach trees, 3 grapevines, 5 small sour-cherry trees, 1 sassafras shrub, 5 plants of field corn, and 1 apple tree. Without disturbing the insects, the sex of the first 10 beetles to arrive on the

plants was noted. When the observations were begun the plants were uninfested. The plants on which these observations were made remained infested throughout the day, and the beetles included in the following data represent the first 10 of an infestation which lasted at least one day. From observations made it was found that

FIG. 20.—Japanese beetles feeding on peach fruit

FIG. 21.—Japanese beetles feeding on peach fruit, and foliage damaged by the insects

15 per cent of the first beetles to arrive were females, 40 per cent of the second beetles to arrive were females, 25 per cent of the third, 30 per cent of the fourth, 50 per cent of the fifth, 30 per cent of the sixth, 20 per cent of the seventh, 40 per cent of the eighth, 55 per cent of the ninth, and 30 per cent of the tenth. There were not

FIG. 22.—Peach fruit partially destroyed by Japanese beetles

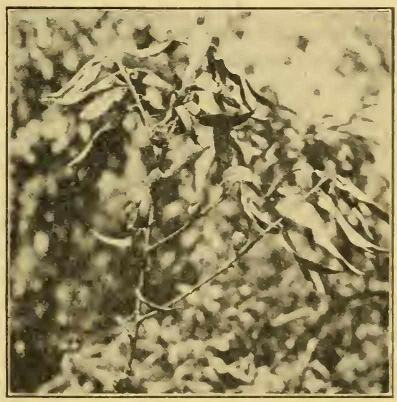

FIG. 23.—Peach branch bearing pits from which the fruit has been entirely eaten by Japanese beetles

fewer than 2, or more than 5, females among the first 10 to arrive on the plants. Data reported elsewhere in this circular indicate that the percentage of female beetles on similar plants during the hours when these observations were made is between 20 and 30 per cent. Therefore, the probabilities are about 1 to 4 or 5 that, on a numerical

basis, male beetles will be the first to infest or reinfest a food plant. On the basis of the data collected one sex is as likely as the other to begin a new infestation, providing there are equal numbers of both sexes flying at the time.

Collections of adult beetles from several different food plants were made in July and August at hourly intervals during the day. Apple trees were selected as representing the taller type of plants; corn, grapes, and rose of Sharon (*Althea rosea*) those of medium height; and smartweed, evening primrose, mercuryweed, and the velvet-leaved mallow as representative of species with low-growing habits. A collection of between 100 and 125 beetles was made hourly at random from the plants. The collections were kept in separate bottles, and later were sorted and the sex determined. It was found that in a series of collections made from smartweed and other low-growing plants between the hours of 7 a. m. and 8 p. m., August 18 to 24, the females constituted between 20 and 30 per cent of the beetles present on the plants. There was a gradual increase in the percentage of females until about noon, when it reached nearly 40 per cent. This proportion did not increase, nor did it fall below 30 per cent until after 6 p. m., when the females constituted about 25 per cent of the beetles on the plants, or nearly the proportion which was found early in the morning.

Collections made from sweet corn and grapes between August 22 and 24 showed that the females constituted less than 20 per cent of the total number of beetles before 8 a. m. and after 6 p. m. Between 11 a. m. and 1 p. m. the proportion of females to males was highest, over 40 per cent of the beetles collected being females. In the case of the grapes the percentage of females continued less than 20 up to 9 a. m., and, except for the two-hour period at noon just mentioned, it varied between 30 and 40 from 10 a. m. to 4.30 p. m. Collections made from Yellow Transparent apple trees July 18, 1921, indicate that until after 8 a. m. less than 20 per cent of the beetles were females. During the forenoon there was a decided increase in the percentage, and from 10.30 a. m. to 2 p. m. it ranged between 40 and 47. Between 2 and 4 p. m. the percentage of females decreased to about 20, and between 5 and 9 p. m. it was 15 to 20.

Tall-growing herbaceous plants, shrubs, and trees are much less heavily infested with the beetles between 4 p. m. and 9 a. m. than they are during the middle of the day. It is evident that during the afternoon there is a more or less definite movement of the female beetles from the tall-growing to the low-growing food plants, and also to the ground for the deposition of eggs. It is also to be noted that low-growing plants, such as smartweed, maintain a higher proportion of females to males throughout the day than do the taller shrubs and trees. As the females move from the tall-growing to the low-growing species there is a corresponding movement of the male beetles to the lower-growing plants. This change of location by the males is much less definite and complete than that of the females. However, in making hourly collections of 100 or more beetles it was a difficult matter to collect the required quota on apples and grapes in the early morning and late evening, whereas at midday thousands could have been collected on the same plants. These daily movements of the beetles may in a measure account for the fact that cer-

tain plants or groups of plants may be heavily infested for a time, after which the infestation will cease, in some cases not to recur during the season.

From the data thus far collected it appears that the females feed somewhat longer on a plant before leaving it than do the males. The amount of foliage consumed by males in a given length of time is slightly greater than that consumed by the females. The rate of food consumption and the time spent by the insects in feeding on their various food plants during the day are undoubtedly greatly influenced and probably largely controlled by the weather conditions prevailing at the time.

SEASONAL LIFE CYCLE

The total life cycle of the Japanese beetle is one year, five-sixths of this time being spent in the soil as an egg, larva, or pupa. Having passed the winter in the soil at a usual depth of between 2 and 4 inches, the larvæ become active late in March or early in April and feed actively until they change to the prepupal stage in May and June. The prepupal stage may last for 10 days or as much as two or three weeks. The larva then transforms to a pupa, and the adult emerges about two weeks later. In some cases the adults may remain in the pupal cells for several days before emerging, but on an average the adults issue from the ground on the second or third day after transformation. The first beetles to emerge are usually found between June 10 and June 20. The average emergence date for females in 1921 was June 20 and for males June 21. Although the first beetles were found June 10 on the heavier soils, it has been found that the beetles emerge from a week to 10 days earlier than on the soil of the sand types. In 1922 the first beetle was found on June 11, and the average date of emergence was June 18.

During 1923 the first beetle was found June 11 and the average date of emergence was June 20. In 1924 the first beetle was found June 21 and the date of emergence was variable until about July 8, when they appeared in large numbers. In 1921, during the period between June 15 and July 15, the average length of the pupal stage was 18.45 days. In 1922 the average length of the pupal stage between June 26 and July 25 was 12.4 days.

The beetles are present through a period of four months and are most abundant during July and August. The long period of occurrence is probably not due to the long life so much as to the fact that the beetles transform and issue over a considerable period.

Although some individuals may feed for several days before mating, others have been observed to mate within two hours after issuing from the soil, and fertile eggs were obtained 24 hours later. Copulation takes place one to several times each day. Egg laying is carried on irregularly throughout the life of the female. The average number of eggs per female obtained in 1922 was 36.94, the largest number laid by one female being 71 eggs. The majority of the females enter the soil late in the afternoon and deposit 1 to 3 or 4 eggs in the night, emerge again the following morning, and feed during the day. The females show a slight preference for sod land as a place in which to lay their eggs. Larvæ, however, have been found abundantly in cultivated fields and orchards, and a few have also been collected in

the soil in wood lots. Under these conditions the eggs hatch in from 10 days to two weeks. The young larvæ feed largely on the smaller roots of such plants as are growing in their vicinity and, to a less extent, on decaying plant products in the soil.

On July 11, 1921, 338 eggs were deposited, and a record was kept of their times of hatching. On July 19, the eighth day after they were laid, three eggs hatched. Nineteen, or 5.62 per cent of those that were laid, did not hatch. Of the remainder, the latest date of hatching was July 25, the fourteenth day after they were laid. A large proportion of the eggs of the Japanese beetle are laid at about this time. More fully expressed in tabular form, the history of the entire lot is as follows:

Date	Day after laying	Hatched	Per cent of eggs laid
July 19	8th	3	0.89
July 20	9th	2	.59
July 21	10th	38	11.24
July 22	11th	161	47.63
July 23	12th	109	32.25
July 25	14th	6	1.78

Did not hatch, 5.62 per cent.

In 1922 several hundred eggs were placed in moist soil and kept at temperatures ranging between 75 and 80° F. The average time required to hatch was 14 days, with extremes of 9 and 27 days; 113 eggs were kept in soil at a temperature of 68° F.; the average time required for these to hatch was 21 days, with extremes of 13 and 28 days. It was noted during the season of 1922 that in every large series of eggs, run for experimental purposes, the hatch was never less than 88 per cent when the eggs were kept in moist soil at temperatures above 55 and below 98° F.

During the fall most of the larval feeding is done in the soil at depths of less than 1½ inches. The larvæ may still feed to some extent during warm days in December, if the soil temperature is 47° F., or above. As cold weather becomes settled the larvæ become quiescent and remain in this condition until spring. No particular cell is formed for passing the winter, and the larvæ, when chopped out of the frozen ground and warmed slightly, will become active within a few minutes.

During the seasons of 1921 and 1922 data were obtained relative to the density of the infestation of larvæ in various soil types occurring in the Riverton, N. J., area. An area 2¼ miles long by 1½ miles wide was divided into 96 equidistant locations. In the spring and fall of 1921, and again in the spring and fall of 1922, diggings each a square yard in area were made at the various locations. The soils in the area thus examined belonged to the Sassafras, Elkton, and Freneau series. Comparing the infestations of the various soil types in 1921 with those of 1922, as shown in the following tabulated statement, it will be seen that the infestation of 1922 represents an increase in density of 57 per cent, as compared with that of 1921:

Soil types	Number of locations examined	Average number of larvæ per sq. yd.	Total number of larvæ	Soil types	Number of locations examined	Average number of larvæ per sq. yd.	Total number of larvæ
Infestation in 1921:				Infestation in 1922:			
Sand	30	36.00	1,080	Sand	30	51.9	1,556
Sandy-loam	33	24.42	806	Sandy-loam	33	66.4	2 191
Loam	33	55.12	1,819	Loam	33	67.9	2,242
All types	96	38.6	3,705	All types	96	62.4	5,989

The greatest increase occurred in the sandy-loam types of soil, and the least in the heavier loams. The times of pupation and of average emergence of the adults were 10 days to two weeks earlier in the loams than in the pure sand types. The distribution of the soil types and locations in relation to elevation indicate that the latter factor, when not exceeding 80 feet, does not influence greatly the infestation of larvæ likely to occur. The depth at which the larvæ feed tended to increase on the soils of a more sandy or open texture.

DISPERSION

NATURAL AGENCIES OF DISPERSION

Since its introduction into Riverton, N. J., in 1916, the Japanese beetle has spread in all directions until at the present time it infests an area of approximately 2,500 square miles. This rate of spread has been fairly consistent in comparison with the increase in the numbers of insects from year to year. The average outward advance from the central point of introduction has been from 10 to 15 miles per year. It is believed that the spread to date has been largely due to natural factors; of these, the most outstanding is the flight of the adult beetle.

The beetle is a strong and vigorous flier and is especially active when the days are hot. Beetles will fly from tree to tree and from place to place for some distance in search of suitable food. The beetles also fly a considerable distance from the fields where they lay their eggs to the feeding places. Individual beetles emerging from the soil have been followed for more than one-half mile. Early in the season suitable food for the beetle is plentiful, and probably the beetles do not fly as great distances as they do later, when the preferred food plants are less abundant. Observations made during the summer of 1922 indicate that there is a tendency for the insects to range farther in search of food in the latter part of July and August than in June and early July. Although it is not possible to say definitely what is the greatest distance which individual beetles can fly, experiments have been conducted bearing on this point, during the course of which marked beetles have been recovered at least a mile and a quarter away from the point of releasement. It is not supposed that this distance was covered in one single flight, but more probably in a series of flights. The beetles normally fly against the wind, and very little flight occurs when high winds are blowing. This fact tends to account for the rather

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uniform rate of dispersion from the infested to the uninfested territory year by year.

Winds and storms probably play some part in the dispersion of the insects. After periods of heavy rains beetles have been observed floating down streams on pieces of wood and other débris carried into the stream by the excess water. Undoubtedly beetles can be carried for some distance in this way. Individual beetles have been picked out of the water of the Delaware River at a distance of several hundred yards from the shore line where it flows through the infested territory. Experiments have shown that the beetles are quite able to float in water with the current unless seized by fish or birds, and possibly they have been carried some distance in this manner, especially along the smaller streams flowing through the infested territory.

It has been found that the beetles are capable of deriving food to a greater or less extent from a variety of our forest trees, although their well-known heliotropic reactions tend to make them resort to more open and brilliantly illuminated areas and to avoid dark and shady situations, such as would be encountered in heavily wooded sections. It is probable, therefore, that the spread of the beetles will be more rapid in open country, where suitable food plants are abundant, than in heavily forested regions.

ARTIFICIAL AGENCIES OF DISPERSION

The dispersion which occurs through agencies which are purely artificial is of considerable importance. Probably the movement of infested materials, such as farm produce and nursery stock, is the greatest factor contributing to the spread of the insect to distant points. In connection with the quarantine regulations which have been and are now being enforced relating to the movement of farm products, the following figures will serve to show the ease with which individual beetles may be carried for comparatively long distances. In the inspection of green or sweet corn during a period of years, beetles were found as follows: In 1919, 23,221 baskets of corn inspected, 77 beetles found; in 1920, 62,139 baskets of corn inspected, 846 beetles found; in 1921, 205,498 baskets of corn inspected, 18,835 beetles found. In 1923 over 32,000 beetles were removed from sweet corn consigned to New York from the Beverly, N. J., district. It should be noted that in every case the corn was inspected after it had been removed from the stalks and piled in heaps at points where there would be little danger of reinfestation by the beetle (fig. 24); the handling of the individual ears incident to their removal from the stalks and their carriage in a sled or similar type of conveyance to the point where the corn was inspected are usually of such a character as to dislodge most of the beetles which may have been resting on the outside of the ear; therefore it is reasonable to suppose that the great majority of the beetles removed during the course of the inspection would otherwise have been carried with the corn to its ultimate destination.

During 1922, 622 beetles were found in 3,459 baskets of cabbage inspected at Riverton. It should be noted that in this case the loose leaves were stripped from the heads of the cabbage before they were inspected and that the majority of the beetles found had actually

worked their way under outer tight leaves forming the so-called head.

Passing vehicles also afford a means of artificial dispersion of the insect, but probably not over as great distances as by the means mentioned in the preceding paragraph. There are many records of findings of beetles on vehicles of all descriptions passing through the infested territory. This fact has also been proven experimentally. A truck was covered with screen wire of coarse mesh, which was smeared over with tanglefoot and along the sides of which was fastened a trough, also smeared with tanglefoot. During the summer of 1921 this truck was driven over a part of the roads through both the heavily and lightly infested areas; many beetles were caught

FIG. 24.—Inspecting sweet corn for shipment to points outside the Japanese beetle area

by the tanglefoot on the wire and along the trough, indicating clearly that many beetles would have fallen into the truck had it not been covered by the wire.

It is probable that automobiles do not play so important a part in the distribution of the Japanese beetle as would appear on first thought. It has been observed many times, not only by the various members of the laboratory force but by private individuals, that beetles will fly into cars, remain for a short time, and then fly out. For this reason it is believed that, in the large majority of cases of beetles which fly to machines passing along the road, they usually escape before the automobile has gone any considerable distance. If any are carried a long distance it is probably because they become entangled in blankets or packages which may be in the machine.

The movement of human beings on foot in and through heavily infested fields may also result in the local dispersion of the insect. For example, beetles have been removed from the clothing of men working in infested orchards after they have left the orchard; beetles have also been removed from the clothing of pedestrians walking along the roads and paths, or through fields, among the heavily infested orchards.

Artificial dispersion over long distances is most likely to result from the shipment of infested nursery stock. All evidence at hand seems to show beyond reasonable doubt that the original infestation in this country resulted from the importation of iris or azalea stock from Japan with the soil about the roots infested with the larvæ of the insect. Several similar cases have come to the attention of the writers, where imported stock of this character, upon examination, has been found to carry living larvæ of Anomala or other related groups.

Experience with nurseries located in the beetle-infested area has shown that stock commonly shipped with soil around the roots, such as potted stock, and the various conifers, can very easily carry living larvæ in the soil and matted roots to any distance over which the stock itself can be safely shipped.

Stringent quarantine regulations affecting the shipment of nursery stock from infested territory have been enforced for several years, and are now being enforced by the quarantine division of the Japanese beetle laboratory staff; so far as is now known these regulations have been effective in preventing further dispersion through this means.

CONTROL

NATURAL CONTROL

Climatological Conditions

As far as the climate is concerned, the Japanese beetle has apparently found in western New Jersey and eastern Pennsylvania exceedingly favorable conditions for its multiplication and establishment. Since the beetle's first appearance in 1916 no climatological condition has offered any check to the rapid numerical increase of the species. Occasionally it has been found that when the eggs are laid in very sandy soil and the weather is particularly dry many of the young larvæ are destroyed owing to the dry condition near the surface of the ground. No condition of heat has been noted which has been injurious to the larvæ or eggs, provided the soil is moist.

When the ground is very dry the larvæ show a tendency to form cells and become somewhat less active than when the soil is moist. During extended periods of rainy weather areas have been flooded for periods of two or three weeks, apparently without any injurious effects upon the larvæ in the soil.

During the past three winters the second and third instar larvæ successfully passed the winter within 2 inches of the surface of the ground, in plowed land. A minimum temperature of 8° F. was recorded 4 inches below the surface. This would indicate that the larvæ can successfully withstand low temperatures.

Diseases

Observations made in 1921 indicated that the larvæ of the Japanese beetle were subject to certain diseases, presumably of bacterial, fungous, or protozoan origin. In 1922 an intensive study of microorganisms affecting the larvæ of the Japanese beetle was begun. It was found that several species of bacteria are highly pathogenic to these larvæ. Some of these organisms have not hitherto been described. One species has been found which kills the larva and causes a partial disintegration of the body within 24 hours after inoculation. Apparently the most probable means of entrance by bacterial infection is through some injury to the larva. There is evidence, however, which points to the probability that infection also takes place through the walls of the alimentary canal of the larva.

Several species of fungi have been found which attack the larvæ under favorable conditions of temperature and moisture. Three species of fungi, including the green muscadine fungus *Metarrhizium anisopliae* Metsch., have at times been found in abundance and attacking the larvæ. During the winter of 1922, cultures of *Isaria densa* were received from the laboratory of Doctor LeMoult, at Nevers, France. In the fall of 1923, plots of ground were inoculated with this fungus and during the spring of 1924 larvæ were recovered from these plots affected with the fungus. Whether fungi will become an important factor in the control of these insects is problematical, because the effectiveness of fungi and bacteria is dependent upon favorable conditions of moisture and temperature. It is planned in the near future to inoculate larger plots in the infested area with the various bacteria and fungi which have been found attacking the Japanese beetle larvæ.

Insect Parasites

The Japanese beetle is not considered an important pest in its native home in Japan, but is to be found in greater or smaller numbers throughout the islands; and although it is sometimes troublesome in certain localities, attacking and skeletonizing the leaves of certain economic plants, it is not known to occur there in such abundance as in the heavily infested areas in New Jersey. From this and the further fact that cultural and climatic conditions are not greatly different from those of New Jersey, it might be supposed that the beetle is kept under reasonable control in Japan by its natural enemies.

The probable value of parasite introduction was so evident that Curtis P. Clausen was sent to Japan in the spring of 1920 to study the beetle and its native natural enemies. In the fall of the same year J. L. King went to Japan to assist Mr. Clausen in making these studies and to expedite the proposed introduction work. Excellent progress has been made since that time, and several large shipments of parasites of various species have been received in this country (*2*).

During the spring of 1920 Mr. Clausen found, at Morioka, Japan, a tachinid parasite (*Centeter cinerea* Ald.) of the beetle. At Sapporo this parasite was abundant in some localities, occasionally

nearly 100 per cent of the beetles bearing its eggs. The egg is usually laid upon the thorax of the beetle, and the larva upon hatching bores downward through the heavy chitinized integument.

In April, 1921, 94 puparia of this tachinid were received at Riverton, N. J. From these seven adults emerged, including both males and females; but, inasmuch as so few were obtained, they were used for experimental purposes and no attempt was made to release them.

In April, 1922, a large shipment of Centeter puparia from Japan arrived at Riverton. In all, Mr. Clausen collected approximately 118,000 puparia. Probably because of adverse conditions, either in holding the puparia or in transit, a large percentage of these were dead by the time they arrived at Riverton. So many came through in good condition, however, that 704 adult flies were released in a suitable location near Riverton during the latter part of June and early July, 1922. A special type of cage was used for the rearing and liberation of the tachinid material, consisting of a square box, the top of which was covered with 24-mesh copper-wire screening; 4 inches below the top was a section of 10-mesh copper-wire screening; below the second screening was a doorway which could be closed at both top and bottom by a sliding glass; near the bottom of the box was placed a tray containing the tachinid puparia. The object of such a box was to permit the hyperparasites, if any occurred, to pass through the coarse screening into the outer compartments; whereas the adult tachinid flies, unable to pass the coarse wire screening, were confined in the doorway by means of the sliding glass. By this method the adult flies could be liberated from the box several times each day, and the secondary parasites drawn off with the minimum amount of handling of the primary parasites to be released. Some difficulty was experienced in handling the flies, since they are extremely active and difficult to rear in confined conditions.

During the season of 1923 approximately 7,000 adult *Centeter cinerea* were released at the same location where releasement was made in the season of 1922. About one week after the parasites had been released beetles were collected in the field bearing eggs, apparently of this parasite. About 200 parasitized beetles were collected and it was found that in nearly all cases the parasite eggs were fertile. No further releasements have been made at this point since that time, and during the summer of 1924 it was found that the parasitized beetles were relatively common over an area of 16 or 17 square miles. This indicates that the parasite has been able to survive the winter conditions obtaining in central New Jersey during the season of 1923–24 and that it has established itself in New Jersey in fairly large numbers. About 2,000 individuals of this parasite were liberated in Pennsylvania during the spring of 1924.

In August, 1920, Mr. Clausen obtained a species of Tiphia parasitic on Popillia larvæ near Morioka, Japan. In April, 1921, 360 cocoons of Tiphia were received from Japan. Two females emerged from this shipment, one of which laid 28 eggs and the other 6 eggs. Cocoons were obtained in the autumn of 1921 from the eggs laid by these females, and adults emerged from them in the spring of 1922.

In the spring of 1922, 811 cocoons were received from Japan. In order to avoid as much loss as possible from fungous disease the

cocoons were placed in individual glass tubes 25 millimeters wide and 120 millimeters long: the bottom of each tube was closed with plaster of Paris, and a single cocoon was placed in each. Only 45 females were reared from these cocoons. As soon as the females had emerged they were placed in a fairly large screen cage with several males and watched until the process of mating had been noted. As soon as the mating was accomplished the females were carried to the field and released.

Further shipments of Tiphia have been received from Japan and released in the field, but as yet no data have been collected indicating that this wasp has become established in the United States.

During the seasons of 1923 and 1924 large shipments of larvæ of the Japanese beetle infested with a dexiid (*Prosena siberita* Fabr.) have been received from Japan. In the season of 1923 several hundred individuals were reared and released in the vicinity of a golf course near Moorestown, N. J. In 1924 over 3,000 adults of this species were reared and released. No data have been collected as yet that would indicate whether this species would successfully establish itself in this country.

The success which was obtained in introducing the Scolia wasp (*Scolia manilae* Ashmead) into Hawaii for the control of the Anomala beetle (*Anomala orientalis* Waterh.), indicated that if this Scolia could be introduced into New Jersey and would successfully become acclimatized to conditions here, it would undoubtedly be a very successful parasite. J. F. Illingworth was employed in the summer of 1922, and between August 3 and September 18, 1922, there were received at this laboratory 9,854 live adult Scolias from Hawaii. Of these, 8,003 were released in areas which were heavily infested with larvæ of the Japanese beetle. It was found that the adult Scolia permanently paralyzes each larva which it stings, whereas when the Tiphia adult stings the larva it paralyzes it only for a short period of time. Apparently the Scolias sting a very large number of grubs before laying any eggs. Under greenhouse conditions Scolias were successfully reared through one generation. Whether they will survive the climatic conditions in New Jersey is questionable.

During the season of 1921 about 1,400 cocoons of *Elis obscura* Fabr. and *Elis quinquecincta* Fabr., which are parasitic on Phyllophaga in Illinois, were collected by T. H. Frison and brought to Riverton, N. J. Attempts were made to obtain eggs from the adults of these species on Japanese beetle larvæ. These were unsuccessful, however, probably owing to the fact that this species normally parasitized much larger grubs than those of *Popillia japonica*. At the same time, 185 Tiphia cocoons were collected in central Illinois, and from these 14 adults emerged. Three of the females laid eggs on *Popillia japonica* larvæ. The eggs hatched, but none of the larvæ matured sufficiently to spin a cocoon.

On December 3, 1921, a shipment of 900 eggs of the moth lacewing *Ithone fusca* Newm. was received from R. J. Tillyard, who collected them on the Hawksbury River, near Sidney, New South Wales. The larvæ of this lacewing are predacious on certain soil-

inhabiting insects. The eggs of this insect are laid separately in the soil, each egg being in a small sand-covered cocoon. The eggs are about 1.5 millimeters long, and in normal conditions require about one month to hatch. These were held over until the spring of 1922 in cool storage. A number of the eggs hatched, but the larvæ all died before reaching the second instar.

Predacious Enemies

During the seasons of 1920 and 1921, Mr. Clausen made shipments of a predacious carabid beetle (*Craspedonotus tibialis* Schaum) which gave promise of being an active enemy of all stages of the Japanese beetle. The species was found in numbers only at Miho, a small peninsula about 100 miles south of Yokohama, Japan.

The larvæ of this carabid are soil-inhabiting and predacious, boring about in the soil and feeding upon soft-bodied insects, mainly white grubs, whereas the adults inhabit more or less permanent burrows in the soil. They apparently prefer sandy embankments. In periods of cool weather they are found well down in their burrows during the day; and in the hotter periods they are frequently observed lurking just within the entrance of their burrow. Most of their feeding is done at night, and the adults feed upon grubs in the soil or upon other insects which they are capable of capturing on the surface of the ground.

The adult beetles were shipped from Japan in small individual boxes similar to the boxes used for safety matches. A small quantity of damp sphagnum moss, but no food, was placed in each box. About 70 of these boxes were packed in a large wooden box, which was nailed tight except for screen openings at each side. The beetles were transferred in the field to a large cage so constructed as to permit close observation of them without allowing them to escape and still have them under natural conditions. The cage covers about 1,500 square feet of ground. The sides are 6 feet tall and covered with wire screening the lower edge of which is buried 3 feet beneath the surface of the ground. The soil in the cage was kept well infested with grubs and was undisturbed.

The beetles when released in the cage apparently made their burrows normally, and mating was observed. Eggs were obtained and larvæ in the first, second, and third instars developed later; apparently, however, they could not survive the winter conditions in New Jersey, as no trace of the live beetles in any stage could be found when the soil was examined in the spring of 1922.

In May, 1921, Messrs. Burgess and Collins, of the gipsy moth laboratory at Melrose Highlands, Mass., sent a shipment of live adult *Carabus nemoralis* Müll. to be tested as enemies of the Japanese beetle. These carabids arrived in good condition, and were placed in cages and fed larvæ of *Popillia japonica* and earthworms. It was found, however, that the adult carabids fed largely at night and only on the surface of the ground. During the day they remained hidden under boards, stones, or other rubbish. Although the beetles readily ate the Japanese beetle larvæ when they occurred

on the surface of the ground, no evidence was obtained to show that they would dig down into the soil to find them. Several cages were prepared with soil in which were placed numerous larvæ of the Japanese beetle. Adults of *C. nemoralis* were released in the cages, but the beetles starved to death, even though there was an abundant supply of larvæ less than 1 inch below the surface of the soil. Further experiments indicated that *C. nemoralis* is decidedly limited in the amount of feeding which it would do on *Popillia japonica*, and that from its habit of feeding above ground it would be of less value than several species of carabids which are indigenous to New Jersey and Pennsylvania.

Collections of live adult *Harpalus vagans* Lec. and *Chlaenius sericeus* Först, were made at Trenton, N. J., by Harry B. Weiss and sent to Riverton. Both species fed on the larvæ of *Popillia japonica.*

The larvæ of *Calosoma calidum* Fabr., *Poecilus lucublandus* Say, *Harpalus caliginosus* Fabr., and *Staphylinus mysticus* Er. have been found to feed on the larvæ of the Japanese beetle.

The larvæ of *Tabanus sulcifrons* Macq. feed readily on the immature forms of Popillia. To some extent *T. atratus* Forst. in its larval stages may also feed on them. At present, however, there is no evidence of any decided increase in the numbers of the various native species which are predacious on *Popillia japonica.*

Birds

Among the natural enemies of the Japanese beetle which are native to the United States, the birds are apparently the most important. The purple grackle or crow blackbird (*Quiscalus quiscula*) and starling (*Sturnus vulgaris*) are common wherever the beetle is abundant, and the writers have found beetle remains in the stomach of the purple grackle, kingbird (*Tyrannus tyrannus*), and cardinal (*Cardinalis cardinalis*); and E. A. Chapin, then of the Bureau of Biological Survey, who made a brief study of the birds in the beetle area in September, 1919, has found beetle remains in the stomachs of the starling (*Sturnus vulgaris*), meadowlark (*Sturnella magna*), and catbird (*Dumetella carolinensis*), as well as of those mentioned above. During the beetle season in 1920, July 8 to August 20, C. W. Leister, also of the Bureau of Biological Survey, studied the birds of the Japanese beetle-infested area in relation to the beetle, and examined the stomachs of 141 birds. He found Japanese beetles in 74 of the stomachs, or 52.5 per cent of those examined. Table 3 is taken from Leister's report. Under "Number collected" is shown the number of birds of each species that were examined. In the next two columns are tabulated for each species the number of stomachs containing the remains of Japanese beetles and their percentage of those examined. The "highest percentage" is the largest percentage of Japanese beetle material found in the stomach of any one bird of the species, and the last column shows the average percentage of this material in all the stomachs examined.

TABLE 3.—*Summary of the results of examination of stomachs of birds, in search of the remains of Japanese beetles*

Name of bird	Number collected	Number with Japanese beetles	Percentage taking beetles	Highest percentage Japanese beetle material in stomach of any one bird	Average percentage of this material in all stomachs examined
Little blue heron (*Florida caerulea*)	1	0			
Bobwhite (*Colinus virginianus*)	3	1	33.3	5	1.6
Mourning dove (*Zenaidura carolinensis*)	2	0			
Sparrow hawk (*Falco sparverius*)	2	0			
Yellow-billed cuckoo (*Coccyzus americanus*)	1	0			
Flicker (*Colaptes auratus*)	3	0			
Kingbird (*Tyrannus tyrannus*)[1]	5	2	40.0	55	11.0
Great crested flycatcher (*Myiarchus crinitus*)	5	2	40.0	45	12.5
Wood pewee (*Myiochanes virens*)	2	0			
Crow (*Corvus brachyrhynchos*)	4	1	25.0	58	14.7
Starling (*Sturnus vulgaris*)[1]	23	14	61.8	98	42.3
Cowbird (*Molothrus ater*)	1	0			
Red-winged blackbird (*Agelaius phoeniceus*)	4	3	75.0	10	7.3
Meadowlark (*Sturnella magna*)[1]	3	3	100.0	92	50.7
Orchard oriole (*Icterus spurius*)	2	0			
Purple grackle (*Quiscalus quiscula*)[1]	29	29	100.0	100	66.3
Goldfinch (*Astragalinus tristis*)	1	0			
English sparrow (*Passer domesticus*)	7	2	28.6	Tr.	Tr.
Vesper sparrow (*Pooecetes gramineus*)	3	1	33.3	40	13.3
Song sparrow (*Melospiza melodia*)	5	1	20.0	Tr.	Tr.
Swamp sparrow (*Melospiza georgiana*)	1	0			
Chewink (*Pipilo erythrophthalmus*)	1	0			
Cardinal (*Cardinalis cardinalis*)[1]	4	4	100.0	84	38.6
Red-eyed vireo (*Vireosylva olivacea*)	1	0			
Ovenbird (*Seiurus aurocapillus*)	1	0			
Catbird (*Dumetella carolinensis*)[1]	9	3	33.3	70	14.8
Brown thrasher (*Toxostoma rufum*)	5	3	60.0	25	13.4
Tufted titmouse (*Baeolophus bicolor*)	1	0			
Wood thrush (*Hylocichla mustelina*)	3	3	100.0	25	6.0
Robin (*Planesticus migratorius*)	7	2	28.6	25	8.2
Bluebird (*Sialia sialis*)	2	0			

[1] Species include 1919 records of E. A. Chapin.

Mr. Leister further says:

These examinations of stomach contents show that the purple grackle accounts for more of the beetles than any other bird. The remains of Japanese beetles were found in all the grackles collected. Several were completely gorged with them, and of all the food taken the beetles made up 66.3 per cent. I observed only three species of birds—the purple grackle, starling, and crested flycatcher—feeding upon the beetles, and of these three only the grackles seemed to have formed a preference for them. In an orchard where the infestation was heavy they could usually be seen feeding and at times pursuing flying beetles. The starlings often fed with the grackles, and on one occasion I saw a flock of these two species feeding together, the grackles keeping to the trees and the starlings to the ground. The beetles on being disturbed by the grackles fell to the ground instead of taking flight, as they would have done had the day been warmer. Owing to this fact the ground-feeding starlings probably found them easier to get than did the grackles.

After the grackle, in importance as predators upon the Japanese beetle, come the meadowlark, starling, cardinal, and catbird, in order. In all, 31 species of birds were collected and 16 had eaten the beetle. The percentage of beetles eaten by the more important birds is as follows: Purple grackle, 66.3; meadowlark, 50.7; starling, 42.3; cardinal, 38.6; catbird, 14.8.

The stomachs of some birds, although not containing the Japanese beetle, had the remains of *Pachystethus* (*Anomala*) *lucicola*, a closely allied insect. These birds undoubtedly also eat the Japanese beetle. They were the sparrow hawk, wood pewee, orchard oriole, and bluebird.

Reports that several birds had been seen eating the beetles were investigated. In one case boys had destroyed the nest of a house sparrow and found five headless beetles in it, the adult birds having evidently pulled off the heads and

fed them to the young. Other instances of the house sparrow having been seen eating the beetles were heard of. This bird, however, is probably of little importance in holding them in check. On one farm quail had been seen eating the beetles. Some patches of smartweed were heavily infested with the insects, and the quail were seen jumping up and taking them from the plants. I talked with the farmers who reported these occurrences and believe their observations to be true.

There is every evidence that the same birds that feed on our common white grubs likewise feed on grubs of the Japanese beetle, and the most important of these are the crow, purple grackle, starling, and bobwhite.

Pheasants are known for their fondness for beetles of all kinds. A pair of English pheasants (*Phasianus colchicus*) furnished by the New Jersey State Fish and Game Commission showed a great liking for both live and dried Japanese beetles. An attempt has been made to colonize these birds in the infested area, and to this end the New Jersey Legislature has passed a law prohibiting the killing of pheasants in certain designated areas for a period of five years, and the Burlington County Game Protective League has distributed pairs in a number of places in the beetle-infested region.

Toads

Toads eat a great many of the beetles and, according to Mr. Leister, the beetles made up an average of 22 per cent of the stomach contents in the seven toads examined. He also reports having examined several lots of toad excrement made up mainly of Japanese beetle shells.

Mammals

No records have been made of mammals feeding on either grubs or beetles, but there is evidence that such animals as the skunk and mole feed on the grubs.

ARTIFICIAL CONTROL

Early Efforts to Eradicate the Insect

After the discovery of this pest in New Jersey strenuous efforts were made to eradicate it. Actual work looking toward its extermination was initiated during the summer of 1918. At that time an effort was made during the period when the adult beetles were present to maintain a continuous coat of poison on the foliage over an area approximately one-half mile wide entirely surrounding the infested territory. Maintenance of a coat of poison on food plants growing along the roadsides was also attempted in order to keep the beetles sufficiently far from the roads to prevent their distribution on vehicles passing through the infested territory. Hand picking of the beetles on a large scale in heavily infested areas purposely left untreated as traps resulted in the destruction of somewhat more than 4 bushels of beetles. Approximately 17 acres of ground were treated with solution of sodium cyanide during the autumn of that year.

During the year 1919 the same general program of eradication was continued, but with more funds available, adequate equipment on hand, and greater experience in dealing with the problem. Noneconomic plants along roadsides through the infested district were

destroyed by various means and poisonous coatings were applied generally to the economic food plants there. Within the heavily infested territory economic food plants were sprayed with arsenate of lead, except in the case of certain areas which were left untreated in order to make hand collections of beetles. In spite of the efforts which were made to reduce the infestation and check the dispersion of the species, the relative spread of the insect that summer was the greatest for any season up to that time.

In the fall of 1919 cyaniding heavily infested fields was continued, sodium cyanide being used at the rate of 165 pounds to the acre, in 12,000 gallons of water, and about 50 acres was thus treated before cold weather made it necessary to discontinue the work. Counts of larvæ in these areas, both before and after, showed the treatment to have been from 90 to 95 per cent effective. Much work was done during that winter in destroying the vegetation on headlands, roadsides, and other waste places.

A final effort was made in 1920 to carry out a program of extermination or to obtain at least a satisfactory reduction of infestation. The barrier band was maintained and noneconomic plants along roadsides were destroyed by means of weed killers of various kinds. Heavily infested orchards within the area enclosed by the barrier band were kept coated with a spray or dust of poison. Unseasonable weather during the height of the beetle season, however, reduced the efficiency of the handwork. One of the most effective efforts of that season was the hand collection of beetles; although figures are not available for the total number of beetles collected by all agencies, boys in the neighborhood who were paid for collecting beetles brought in 1,899 pints of them during the season.

At the close of the 1920 season it appeared that the spread of the insect to the south and west had apparently been lessened to a considerable extent, but the spread to the north and east was very much greater, as shown by the map (Pl. I). It was felt by those in charge of the work that the effort to secure reduction, or even satisfactory control, did not produce results justifying further efforts along this line. A thorough study of the situation showed that, in spite of the work, extermination or eradication or even reasonable control had not been secured; on the contrary, the insect had rapidly increased in numbers year by year and the area of infestation had become greater each season. It seemed evident that under these conditions extermination of the pest could not be anticipated within any reasonable expenditure of funds, and all thought of a policy of eradication was given up. A consideration of the increase in numbers of the beetle and the spread of later years has fully justified this decision.

Quarantine on Account of the Japanese Beetle

The early realization that the Japanese beetle was a potentially serious insect pest led to the inauguration of a quarantine in 1918 by the New Jersey State Department of Agriculture. Since that year quarantines have been promulgated by the Federal Horticultural Board and by the States of New Jersey and Pennsylvania. The first quarantine included only sweet corn, since at that time it was

felt that this was the commodity most likely to carry the insects from points within the infested area to points outside. As the area has increased and the beetles have become more numerous, the quarantine requirements have changed until, during the season of 1923, sweet corn, cabbage, lettuce, and grapes were regulated, as well as soil, compost, and manure, and general nursery, ornamental, and greenhouse stock. (See fig. 25.)

RESTRICTION OF MOVEMENT OF NURSERY STOCK

Since the inception of the quarantine against the Japanese beetle, restricting, regulating, and safeguarding the movement of nursery stock and other plants has been recognized as perhaps the most important phase of the quarantine control work, and during this whole period every care has been taken to make it the most effective

FIG. 25.—Soil removed from a pot, exposing four live Japanese beetle grubs. The object of the quarantine on nursery plants and soil is to prevent shipment of such infested material to points outside the regulated area

possible. (See fig. 26.) These efforts, so far as known during the five years of quarantine control, have entirely prevented the distribution of the insect by means of nursery products. The quarantine on account of the Japanese beetle is known as Quarantine No. 48, and has been revised several times, the latest revision becoming effective April 9, 1924. The risk of spread of the insect with such stock is almost entirely concerned with the possibility of carriage of the larvæ in soil about the roots of plants. The adults are out from June 15 to October 15, but principally during July and August; the larvæ, on the other hand, are present in the soil throughout the year, and the main object of the nursery quarantine is therefore to prevent their distribution. There is but little danger of distributing the adults on nursery stock, since but little stock is handled during the months when the beetle is on the wing. Added precautions, however, are taken to prevent any such distribution.

The area to which the restrictions of this quarantine on the shipment of nursery stock, etc., applies includes the entire known infested area and, in addition, a safety border zone of approximately one township in width. This area is determined by annual scouting, carried on during the period of flight of the beetle, June 15 to October 15. Since a safety zone of about one township in width is maintained around the known infested area, and since the adults will be found toward the periphery of the actually infested area two or

Fig. 26.—Road sign 4 by 7 feet warning against carrying contraband products out of the area quarantined for the Japanese beetle

three years in advance of the occurrence of the larvæ in any appreciable quantity, the result is that many nurseries included within the Japanese beetle area are not infested. Nevertheless all such nurseries are immediately brought under the operation of the quarantine and receive careful supervision and inspection, and no stock is allowed to be shipped therefrom except under the restrictions specified in the quarantine regulations. On account of the fact that some nurseries are infested and others are not, nurseries throughout the general

Japanese beetle area have been classified into three different groups with respect to the danger. These are (1) nurseries, so far as can be determined, entirely free from invasion either by adult beetles or by larvæ in the soil; (2) nurseries in or near which a single adult beetle has been found, but in which no soil invasion has been determined; and (3) nurseries in which both beetles and larvæ in soil occur.

Nurseries of the first class are those usually in or near the safety border zone of the Japanese beetle area and in townships or districts where neither beetles nor larvæ have been found. With the nurseries of this class blanket certification is made for the movement of stock, and certificates for this purpose are issued to the nurserymen.

With respect to nurseries of the second class, nursery stock with soil may be certified for shipment, provided careful and frequent diggings have been made throughout the nursery blocks and no larvæ have been found, and also provided that the soil is examined and inspected at the time of digging. In addition to such examination the first 2 or 3 inches of surface soil are removed from about the plant, for the reason that during September and October and during April and May, the two chief shipping periods for evergreens and other field plants, any larvæ, if present, would be most likely to occur near the surface.

No nursery stock or soil is allowed to be shipped out of the Japanese beetle area from nurseries of the third class, except certain kinds of plants, in digging which it is possible to treat the soil by methods which have been determined as being 100 per cent effective in killing the larvæ. Stringent regulations in addition to those mentioned are enforced, particularly with respect to certain classes of nursery stock, the use of certificates, and the furnishing of information covering the transactions between dealers in various kinds of nursery stock within the area.

QUARANTINE ON FARM PRODUCTS

Until the season of 1924 sweet corn, cabbage, lettuce, and grapes were the articles included under the farm-products quarantine. The quarantine on farm products is operative between June 15 and October 15, the period when the adult beetle is present and likely to be carried out of the infested area on produce of various kinds. Until the summer of 1923 all restricted farm produce was inspected at the point where grown, or at least on the farm. Owing to the increase in size of the infested area in 1922, the greater cost of inspection at points of origin, and the fact that the city of Philadelphia then came within the infested area, the method of carrying out the farm-products quarantine in 1923 was changed from one of inspection at the farm or point of origin to a zone system. Taking the Philadelphia market district as a center, a zone was established with a radius of approximately 25 miles. All produce originating within the infested area and consigned to the Philadelphia market was allowed unrestricted movement within this zone. It was recognized that farm produce moving from the infested area to more distant points, as, for example, New York, Atlantic City, Allentown, and Wilkes-Barre, should be inspected; but since this could not be done in the markets, it was inspected and certified at the point of origin

and shipped direct to its destination. By provisions of the State and Federal quarantines the movement of inspected produce from the Philadelphia market to points outside the zone was prohibited.

This system worked satisfactorily during the season of 1923. However, it was found that when the unrestricted movement of farm produce was permitted from the infested areas to the Philadelphia market thousands of beetles were carried to the market daily in corn and other produce. In the market district the nature of the commission business renders it impossible to segregate produce originating from various points. Such a situation made it possible for many kinds of produce emanating from the Philadelphia market to be infested with beetles. As a result, during the season of 1924 it was necessary to prohibit the shipment of any farm produce from Philadelphia to points outside of the regulated area, except articles grown outside of the Japanese-beetle area. These were permitted to be reconsigned from Philadelphia, provided each package or container was marked with the name and address of the grower; such shipments were required to be transferred direct from car to car at the freight yards or docks. As a second provision, certain articles of fruit, including cherries, grapes, peaches, apples, plums, pineapples, and citrus fruits, grown outside the infested area and shipped in tight containers, were, upon certification, allowed reshipment in the original containers from any point in Philadelphia. Potatoes, okra, eggplants, tomatoes, cantaloupes, and cabbage were allowed to be shipped from points in Philadelphia to points outside the Japanese-beetle area, provided they were inspected and certified by an inspector of the Department of Agriculture.

Enforcement of the farm-products quarantine in 1924 was conducted along much the same lines as in 1923. Inspectors were placed at the boundary of the quarantine zone on all the important roads leading out of the Japanese beetle area. It was their duty to intercept all illegal shipments passing over the roads and to obtain the necessary data for the conviction of willful violations of the regulations. To insure the necessary inspections of restricted articles emanating from the Philadelphia markets, corps of inspectors were maintained in the freight yards and at three inspection points in Philadelphia, where the necessary inspections of produce were made.

Corps of inspectors are also maintained at strategic points throughout the heavily infested region, subject to call by growers wishing to make direct shipment from the farm or point of origin to a destination outside of the regulated area. On application from the grower the necessary inspectors are sent to his premises, his shipment is inspected, and if found free from Japanese beetles it is so certified. During the summer of 1924 nine suboffices for inspectors were maintained at various points in the regulated area.

In addition to the personnel for enforcement of the quarantine, corps of scouts are maintained during the summer months of each year to ascertain the distribution of the Japanese beetle. This is done by scouting on the outskirts of the infested area until beetles are found. In the fall, when the scouts' reports are complete, the outermost points where the Japanese beetles were found are connected, and the infested area is designated by the boundary lines

so drawn. Scouts are also maintained in neighboring States, and careful scouting is done in the vicinity of Baltimore, New York, Pittsburgh, and many other points where the beetles are most likely to be carried.

Control of the Larvæ of the Japanese Beetle

A great deal of experimental work has been performed for the purpose of finding effective methods of destroying the larvæ of the Japanese beetle. In general, the work has been carried on along two main lines; the control of the larvæ where they occur in large numbers in pastures, lawns, golf courses, and similar places, and their destruction in the soil about the roots of the various types of nursery stock intended for shipment to points outside the regulated area [area (F).] (7)

CONTROL OF THE LARVÆ IN GRASSLAND

A number of chemicals have been used in attempts to control the larvæ of the Japanese beetle in grass sod, but in most cases the limiting factor has been the excessive cost of the materials and the cost of the labor necessary in their application. During the early extermination work use was made of sodium cyanide in solution. This material was satisfactory from the standpoint of its toxic effect on the grub, but it was distinctly injurious to the sod, and the cost of labor, material, and special equipment for applying the solution was so great as to preclude its use on a large scale. Among the many other materials which have been tested are paradichlorobenzene, orthodichlorobenzene, and calcium carbide. Of these, only paradichlorobenzene gave satisfactory results. When it was drilled into the soil at the rate of 300 pounds to the acre, as high as 75 per cent mortality of the larvæ could usually be obtained. At present prices, however, the cost of materials amounts to about $60 per acre; and, since it is effective only in fields where conditions are suitable, its usefulness for this purpose is limited.

A practical method of destroying larvæ in large numbers on golf greens has been devised (*6*), consisting of treating the soil with a dilute solution of carbon-disulfide emulsion. The emulsion is prepared by mixing 1 part by volume of cold-water-soluble resin-fishoil soap, 3 parts of water, and 10 parts of carbon disulfide. The soap and water should be agitated in a churn (an ice-cream freezer is also very satisfactory for this purpose) until an even mixture is obtained; to this the carbon disulfide is added and the whole churned until it emulsifies, as indicated by a change in color and a creamlike consistency of the liquid. One quart of the emulsion thus obtained is stirred into 50 gallons of water, and the resulting mixture is applied at the rate of 3 pints to each square foot of turf. In order properly to treat a golf green the turf should be maintained in a moist condition for at least 10 days prior to the application of the insecticide. The green should then be laid off into areas of about 1,200 square feet and the proper quantity of solution applied to each area. Formerly the mixture was run on to the green from a spray tank. (See figs. 27 and 28.) This method of procedure has been improved

upon, and in the fall of 1924 a special attachment was put on the market, to be connected to the water main for regulating the quantity of insecticide entering the water stream, thus eliminating the use of a tank. In applying the material care should be taken that the turf is not flooded. The liquid should be applied lightly and allowed to soak in and the operation repeated until the required quantity of solution has been used.

CONTROL OF THE LARVÆ IN NURSERIES

The quarantine regulations which have been and are now being enforced for all classes of nursery stock which are commonly shipped with soil about the roots require before such shipment is permitted

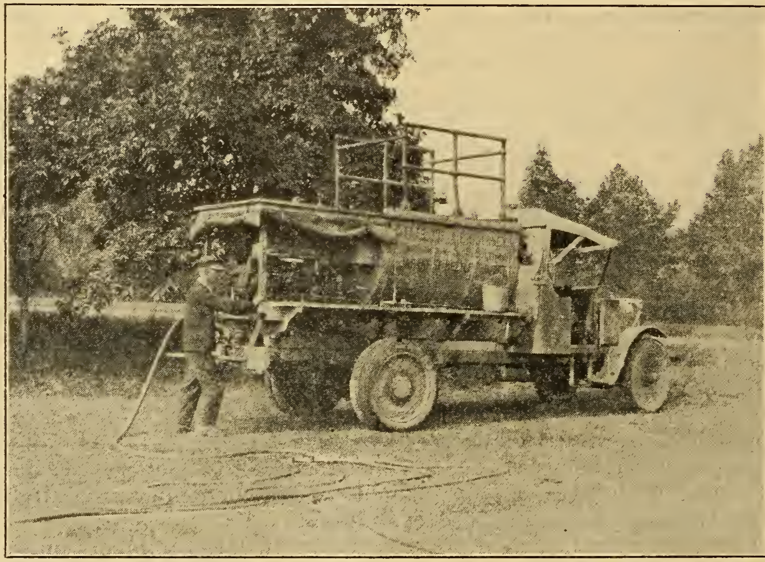

FIG. 27.—Tank and special outfit used in experimental work in treating sod with carbon-disulfide emulsion to destroy the larvæ of the Japanese beetle

the treatment of the soil in such a manner as to insure the death of any stage of the Japanese beetle which it may contain. Much experimental work has been done to devise means of treating the soil ball under these conditions so as to make it free of infestation by living larvæ. (See figs. 29 and 30.) By providing coldframes with netting between the frames and the sash, adult beetles have been excluded from them, and ventilation has been provided without the necessity of raising the sash (fig. 31).

Certain arsenates, such as those of lead, iron, zinc, and copper, have been mixed in varying quantities with the soil in which potted plants are grown, with the object of obtaining larval mortality with no accompanying plant injury; of these, acid lead arsenate has given the most satisfactory results. In the case of acid arsenate of lead, results to date have shown that many plants grown in soil treated with this material are entirely resistant to any ill effects and others

are slightly injured, but some species are very susceptible and suffer considerable injury from the effect of the arsenical in the soil.

Attempts were made to kill the larvæ in soil by means of several so-called contact insecticides, among which may be mentioned bichloride of mercury, various cresols, phenols, petroleum, mineral oils, and other materials, but in all cases they have proved to be injurious to plant growth when used at dosages toxic to the larvæ.

More than 40 organic chemicals have been used in treating infested soil balls, among them being ether, petroleum-ether, toluene, acetic-ether, nitrobenzene, chloroform, and others. In most cases these have been found more or less toxic to the larvæ, but the resultant injuries to the plants have been such as to preclude their use for this purpose.

FIG. 28.—Method of applying carbon-disulfide emulsion to a green at the Country Club, Riverton, N. J.

Several greenhouse concerns within the infested territory are now using a method, worked out by this laboratory, for fumigating their potting soil (*3, pp. 40–41*) (fig. 32). It is summarized as follows:

Carbon disulfide must be placed in the soil to kill all the larvæ.

It seems advisable to use not less than 13 fluid ounces (1 pound) to a cubic yard of soil with an exposure of 48 hours at a temperature above 50° F.

Dosage holes must be arranged so that the diffusions regions from the various injection holes overlap and thus assure all parts of the soil being treated. It is suggested that when 18 inches of soil has been placed in the fumigation box, injection holes should be made 6 inches deep in rows 12 to 15 inches apart and 12 to 15 inches distant in the rows, with 1½ ounces of CS_2 in each injection hole. After closing the hole, 18 inches more soil are placed in the box and the process is repeated until the box is filled.

Experiments have been carried out to test the effect of vacuum, pressure, and their alternation, upon the larva and the plant. The apparatus used was specially designed for these studies and has a

working range from 28 inches of vacuum to 150 pounds pressure. The results from a practical standpoint have been negative in that the effects upon the plant and the larva have been similar, being a rupturing of the tissues of both the plant and the insect when any sudden change from atmospheric pressure is made. Gradual changes from the normal proved to be neither harmful to the larva nor injurious to the plant. When various gases were used as fumigants under vacuum or pressure, the results were practically the same as when the same materials were used under normal conditions.

Experiments with hot water to kill the larvæ in the soil have been carried out by Leach (*4*), and show that water at a minimum tem-

Fig. 29.—*1*, Boxwood with original soil ball around roots cut in half to show texture of the mass of soil and roots; *2*, boxwood from which the original soil ball was removed by washing and replaced by soil free from larvæ of the Japanese beetle. The new soil ball cut in half to show how closely the remade ball corresponds to the original

perature of 110° F. will kill the larvæ immersed in it for 45 minutes, but when the roots of living plants are subjected to the same treatment even the more resistant varieties are likely to be seriously injured.

Detailed studies have been made by Leach and Johnson on the use of various chemical dips for destroying the larvæ in soil about the roots of plants such as Japanese iris, phlox, and sedum. The results of the work, published as Department Bulletin 1332, indicate that oil of wormseed and caarbon disulfide are the best materials for use in this connection. These compounds when emulsified with soap are both capable of forming stable emulsions, the toxic principles of which are retained indefinitely. The active ingredient of oil of wormseed is ascaridole, $C_{10}H_{16}O_2$. Certain other constituents of the oil are also toxic in varying degree. The

concentration of the dip as recommended is stated in terms of the ascaridole content of the oil. When the Japanese beetle larvæ are immersed for six hours in the wormseed oil dip, the concentration of which is equal to 0.5 cubic centimeter of ascaridole to 3 liters of water, the larvæ are killed, provided the temperature of the dip is maintained between 65 and 70° F. Temperature is a limiting factor in this treatment, and under no circumstances must it be allowed to fall below 65° F. The general recommendations are that Japanese iris and sedum be immersed for 15 hours, and perennial phlox from 9 to 18 hours, depending upon the quantity of soil present in the roots. These periods of time provide an ample margin of safety over the time actually required to obtain the death of the larvæ.

Fig. 30.—Experimental plots showing evergreens used in testing treatments in the soil insecticide investigations against the Japanese beetle

It has been found advisable, from the standpoint of cost, to employ carbon-disulfide emulsion for the treatment of peony roots. The plants are immersed for a period of 15 hours in a dip the concentration of which is equivalent to 0.5 cubic centimeters of carbon-disulfide emulsion in 1 liter of water.

Carbon-disulfide emulsion is also being used extensively for the treatment of many other kinds of plants with soil about the roots, including arborvitae, spruces, hemlocks, rhododendrons, azaleas, blueberries, hydrangeas, ferns and similar plants, besides numerous varieties of potted stock.

Control of the Adult Beetle

It has been observed from the earliest days of the work that arsenicals, such as acid arsenate of lead and Paris green, act as decided

repellents to the beetle. Advantage was taken of this fact in the earlier barrier-band work, since it was believed that arsenate of lead, because of its repellent effect upon the beetles, would prevent them from spreading into noninfested territory when the foliage was thoroughly coated with the arsenical. It has also been found that the actual killing resulting from the use of the arsenicals was probably not more than 15 or 20 per cent. At first it was believed that this low percentage of mortality was due to the fact that the odor, taste, or physical nature of the arsenical repelled the beetles from foliage which had been sprayed. Subsequent investigation, however, has shown that these are not the only factors responsible for the repellent effect of arsenicals, but, as reported by Moore (*8*), the beetles

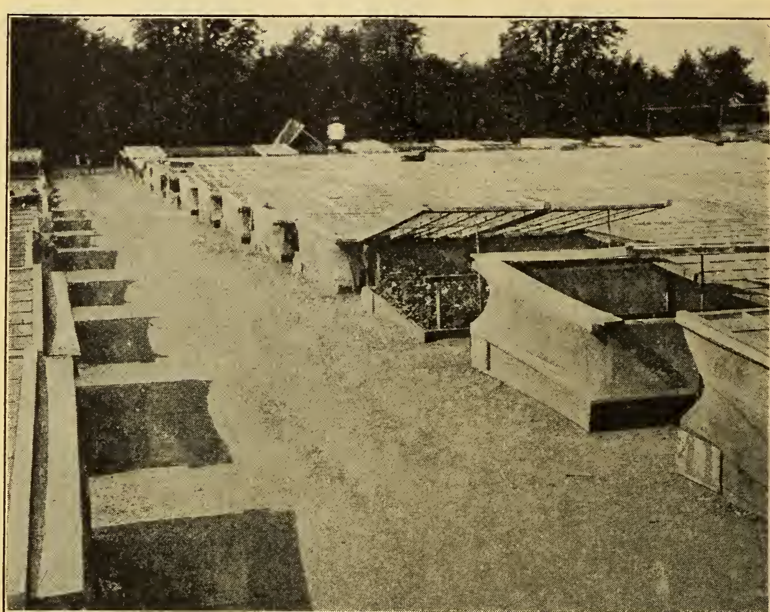

FIG. 31.—Cold frames with netting between the sash and the frames which permits ventilation without the necessity of raising the sash. In this way invasion by the adult Japanese beetle is prevented

appear to be repelled also by the toxic symptoms resulting from eating a certain amount of the arsenical. Many experiments have been carried out in the last several years in order to determine what results the standard arsenicals, particularly arsenate of lead, may give in obtaining a definite killing of beetles, as well as in the protection to the foliage obtained through the repellent action of the material. During the course of this work many different combinations of the various standard arsenicals, with and without the addition of other materials, have been tested.

Many beetles apparently feed to some extent on sprayed foliage, but owing to the strongly alkaline saliva of the beetle the acid arsenate of lead breaks down quickly, presumably causing an irritating action on the alimentary canal of the insect. This action, it is supposed, causes the beetles to stop feeding, with the result that

the large majority have not consumed a toxic dose of the poison. It was thought that by adding to the arsenate of lead some material which was only slightly soluble and rather slowly acted on by the body juices of the insect the action of the arsenical would be delayed and the beetles would eat so much of the sprayed foliage that by the time they felt the effects of the poison they would have consumed a killing dose.

Various arsenicals such as arsenate of lead, zinc arsenite, and calcium arsenate were mixed with various soaps having lead, zinc, or aluminum bases, and prepared from various fatty acids such as stearic, oleic, linoleic, clerpanonic, and ricinoleic acids. In all about

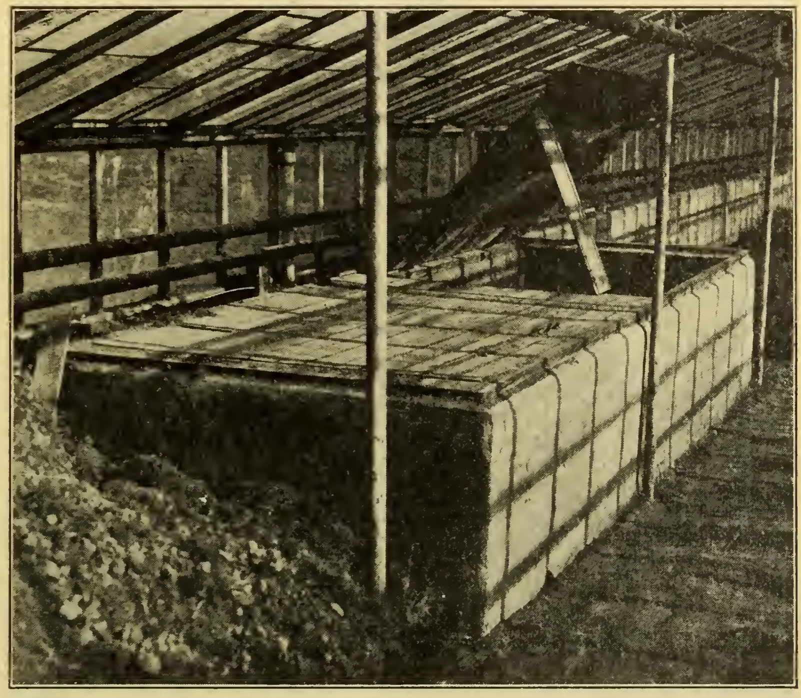

Fig. 32.—Concrete tank for fumigating soil with carbon disulfide to destroy the larvæ of the Japanese beetle

96 of the different soaps were used. It was found that the mortality obtained with the mixtures was higher than with the arsenate of lead alone. The presence of the soaps in most cases greatly improved the spreading and sticking qualities of the spray mixtures (figs. 33 and 34). The cost of the materials in the soap preparations is between 1 and 2 cents a pound greater than the cost of arsenate of lead paste.

The recommendations which have been made for the protection of foliage against the attacks of the adult Japanese beetle have been to use the standard arsenate of lead, with or without a sticker and spreader, such as flour or calcium caseinate. It has been found that arsenate of lead at the rate of 3 pounds to 50 gallons of water, with the addition of 2 pounds of flour, has given fairly good protection to

the foliage of apples, grapes, and ornamental trees, provided that an absolutely thorough job of spraying is done. Not only must the spraying be thorough, and all portions of the foliage and fruit be covered with the poison, but the coat of spray must be maintained throughout the season when the beetles are abundant. Many of the growers in the infested area are applying sprays with excellent

Fig. 33.—An apple tree defoliated by the Japanese beetle, on which new growth has started at the tips of the branches. This tree was not sprayed previous to or during the prevalence of the Japanese beetle

results, following the directions issued by the laboratory at Riverton. On the other hand, no destruction of large numbers of the beetles over an extended area can be obtained by this method of treatment.

Besides the studies of arsenicals as poisons for the Japanese beetle much experimental work has been carried on with stomach poisons other than arsenicals, and a great many inorganic and organic materials have been tested. Some of these are known to have toxic

properties; others have been found inefficient from the standpoint of their toxic effect on the insect.

Leach and Brinley (*5*) found that a soybean-oil soap solution will give fairly satisfactory results when used as a contact insecticide against the Japanese beetle. During the summer of 1922 results were obtained which showed that soybean-oil soap when used

Fig. 34.—An apple tree which received one spray of coated arsenate of lead at the time the beetles first appeared. It is apparent how completely the foliage was protected from the attacks of the insect

at the proper concentration is quite efficient as a contact spray. Great care must be exercised, however, in obtaining a pure and satisfactorily compounded material. Several of the so-called soybean-oil soaps, such as are now on the market, proved upon analysis and field tests to contain ingredients which would sometimes cause injury to the foliage. Further studies are necessary before it is

safe to recommend them for general use. One must be obtained which can be manufactured by standardized formulas from constitutents which are themselves sufficiently standardized to give a uniform final product. It should be borne in mind that the use of a contact spray of this character for the Japanese beetle will be limited to the killing of large numbers of beetles concentrated in small areas.

Various proprietary insecticides to be used in destroying the Japanese beetle have been placed on the market by manufacturers. It has been found that some of these will kill the beetle without serious injury to the foliage of the plants which are sprayed. On the other hand, many of the proprietary materials are more in the nature of disinfectants, usually an emulsion of soap, and creosote, carbolic acid, or some of the essential oils. Materials of this nature usually cause severe injury to any foliage on which they are sprayed.

It has been realized for several years that, in addition to a spray of an arsenical or arsenical substitute, it would be extremely valuable to have a material to spray on ripening peaches which would have a decidedly repellent effect on the beetles. Such a material should preferably be an emulsion or solution which would leave on the fruit no residue, odor, or discoloration that might be objectionable when the product reached the market. In addition to a repellent it is also desired to obtain a material which is decidedly attractive to the adult beetle. Investigations to this end have been carried on for the last three years, and it has been found that several of the essential oils are highly attractive to the Japanese beetle. On studying the various constituents of these oils, it was discovered that one of the higher alcohols, geraniol, is a constituent of all the oils found to be distinctly attractive. Tests have been made of a series of the preferred food plants, and in all cases these plants contained geraniol in varying amounts. The possibility of utilizing this chemical in a spray mixture is under investigation.

Control experiments in apple, peach, and cherry orchards and grape vineyards are being conducted for the purpose of determining the value of the various spray mixtures and compounds as insecticides against the Japanese beetle. (Fig. 35.) During the season of 1924, approximately 100 acres of orchard was used for this purpose. Excellent results have been obtained in the protection of both fruit and foliage, even in the areas which have been infested the longest, and where the beetle population is most dense.

CONTROL OF THE JAPANESE BEETLE ON APPLES

Early and late ripening varieties of apples should be sprayed with a mixture of 3 pounds of powdered arsenate of lead and 2 pounds of flour (gluten content at least 12 per cent) to 50 gallons of water. Mix the arsenate of lead and flour dry, then add water to make a paste, dilute, and strain into the spray tank. In order to protect the foliage and fruit from the attacks of the beetle, it is necessary to have the spray applied before the plants become infested. The exact time for doing this varies somewhat with the season. In the seasons of 1921, 1922, and 1923 the sprays should have been applied and the operation completed not later than June 25. In the season of 1924,

however, it was possible to withhold the beetle sprays until the week ending July 14. In general, however, it is recommended that growers should arrange to have their spraying completed not later than June 25. Should heavy rains occur and much of the spray be washed off the plants, it may be necessary to repeat the application 10 days or two weeks after the first spraying, in order to maintain a coat of poison on the fruit and foliage. In order to protect the plants and control the beetles, the spraying must be thoroughly done.

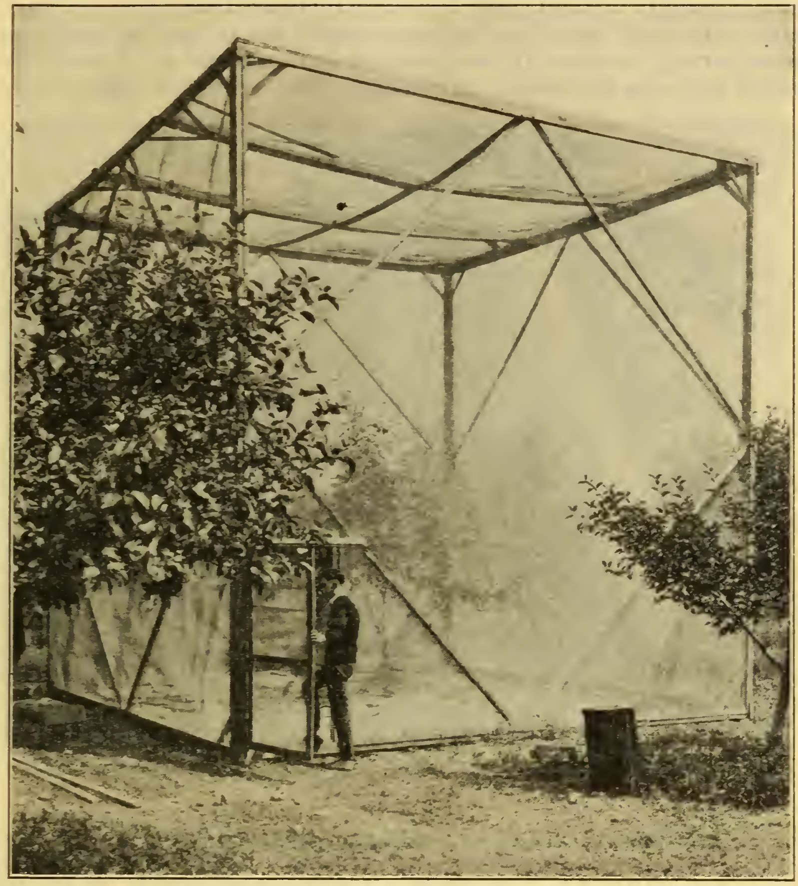

Fig. 35.—A field cage for inclosing infested fruit trees which are sprayed with various materials, to determine the percentage of the beetles killed. The ground in the cage is entirely covered by canvas. The dimensions of the cage are 20 by 20 by 20 feet. It is built in sections and is readily movable from one place to another

This means that the foliage and fruit must be completely covered by a film of the spray. It is of particular importance to cover all portions of the foliage in or near the top of the tree, since the beetles first attack the upper and outer portions of the plant. If an infestation can be prevented much better results will be obtained than if an attempt is made to drive the beetles from the plants after they have once commenced to feed on them. In the case of early apples sprayed shortly before the time of harvest, it is advantageous to

have the pickers wear cotton gloves and wipe the fruit when it is harvested, unless it is intended to run the fruit over a grader or other machine equipped with rotary brushes which will remove any arsenical deposit.

CONTROL OF THE JAPANESE BEETLE ON LATE PEACHES

Peaches of the Carman variety or varieties which ripen later in the season may be sprayed with 1½ pounds of powdered arsenate of lead, 2 pounds of flour, and 3 pounds of stone lime to 50 gallons of water. In most cases the Japanese beetle spray can be applied on late-ripening varieties if the spraying is completed by June 25 or a month previous to the time of harvest. This will give sufficient time

FIG. 36.—Using a high-power sprayer to spray ornamental trees in the golf course at Riverton, N. J.

for the arsenate of lead to be washed off the fruit by rains before the fruit is marketed. As in the case of apples, a thorough application of the spray must be made to insure adequate protection. It has been found that on trees 10 to 12 years old at least 4 gallons of spray mixture is required for each tree.

CONTROL OF THE JAPANESE BEETLE ON CHERRIES, GRAPES, AND ORNAMENTAL TREES

Both sweet and sour cherries, grapes, and various ornamental trees, such as lindens, elms, horse-chestnuts, and ornamental shrubs, including roses, althea, etc., may be protected by spraying them with the arsenate of lead formulas recommended in the case of apples. As with other fruit, the spraying should be completed by June 25, and the necessity for doing a thorough job can not be overemphasized. (See fig. 36.)

CONCLUSION

The importance of the Japanese beetle in the area where it now occurs and the damage which it may cause when introduced into regions which are not as yet infested are mooted questions. Those who have not seen the damage done by the insect should not be misled into believing that it causes a wholesale defoliation of the trees and a devastation of the crops. The gregarious habits of the insect result in heavy infestations in certain localities where it has occurred for a number of years. Its preferred food plants, unless properly protected by sprays, are to a large extent defoliated. Neighboring localities, however, may have very few beetles and little damage would be apparent to a casual observer. In the region most heavily infested at the present time the injuries are found to occur on a wide variety of plants. In central New Jersey large acreages of early and late ripening varieties of fruits, sweet and field corn, cereal, forage, and vegetable crops are grown, in addition to innumerable shade and ornamental trees and shrubs. The losses sustained by the New Jersey growers through the damage done by the beetles to any one particular crop are probably less than would be the losses if the beetles occurred in a locality where fewer crops are grown and a smaller number of them affected. The Japanese beetle feeds on cotton, on the blossoms and foliage of red clover, on string beans, and on various other plants. It is believed that if the insect should be introduced into an area where environmental conditions were favorable and these or similar plants were grown extensively, the damage done to such crops would be much greater than the damage already wrought under the conditions obtaining in New Jersey.

It has been found that any plants which can be sprayed with an arsenical poison may be successfully protected against the attacks of the Japanese beetle. From the standpoint of the production of fruit or protection of shade trees, this insect does not offer a menace which can not be prevented or controlled. When the beetle occurs abundantly in fruit-growing sections or residential districts, however, the growers will be subjected to an additional expense to protect their plants from a more or less serious loss. If this insect should become distributed widely the total expenditure of money by the people to protect their plants and crops would in the aggregate represent an enormous amount. As it happens, an additional spray is required on most fruits to prevent the attacks of the Japanese beetle. It can therefore be considered that, even with effective methods devised for the protection of crops, an additional expense is placed on the people in communities infested with this insect.

It appears that the insect will normally spread outward at the rate of between 10 and 15 miles each year, unless it is carried to a greater distance through some artificial agency. The operation of the quarantine on farm produce and on the movement of nursery stock with soil about the roots has thus far apparently been successful in preventing the extensive spread of the insect. The experience of those operating the quarantine indicates that the time will come when a change may be advisable in the method of enforcement. As the insect continues to spread it will probably reach particular areas which will at least temporarily, if not permanently, stop its movement in certain directions. Such barriers may be either ecological or topo-

graphical in character. Quarantine lines could be arranged to follow the areas where the beetle is checked naturally in its spread. Under these conditions embargo action on farm produce moving from the infested area might be advisable, as well as a continuance of the strict regulation of the movement of nursery stock and infested soil. A quarantine thus established would in all probability be effective for many years in preventing the long-distance spread of the beetle. It is obvious that, while a quarantine over a relatively large area means the expenditure of large sums of money it will be more than justified if the spread of the insect can be prevented or held back for several years. If the quarantine were to be dropped and the beetles were to spread over a large territory, the losses which would result, both through the destruction of crops and in the expenditure of funds for their protection, would in the aggregate constitute a sum greatly in excess of the amount necessary for quarantine purposes.

The outlook at the present time is most hopeful. The development of spray materials which are giving excellent protection to plants as well as a definite killing of the insects, and the finding of effective methods of their application, afford the fruit growers and others a means of preventing serious losses. The method of soil treatment worked out for the control of the grubs offers relief to those who have been suffering damage to their sod lands. The establishment of at least one species of parasite of the Japanese beetle in this country will undoubtedly result in a gradual diminution in numbers of the beetle. There is every reason to believe that the Japanese beetle will gradually be brought under control and its injuries almost if not entirely prevented.

SUMMARY

The Japanese beetle, an insect native on the islands of Japan, was introduced into the United States in the vicinity of Riverton, N. J., some time prior to 1916. Since that time it has increased in numbers and spread until at the end of the summer of 1923 it had infested an area of approximately 2,500 square miles in New Jersey and Pennsylvania.

From the rate at which the insect has increased in numbers since it was introduced and the extent of its spread, it is evident that its soil and food requirements as well as needed conditions of moisture and temperature have been met in a manner most satisfactory for the development of the insect. It is probable that soils which are neutral or slightly acid in reaction and an open campestral country, abundant in permanent sod lands and supporting a rich growth of mesophytic vegetation, is most satisfactory for the development of the Japanese beetle.

The insect has been found to feed on about 200 species of plants in New Jersey. These include practically all the economic crops, although the following are preferred: Apple, quince, peach, sweet cherry, plum, grape, blackberry, clover, soybean, and corn; the shade trees attacked include linden, birch, oak, elm, sassafras, horsechestnut, and willow; ornamental shrubs, particularly althaea and rose, flowers of all kinds, and many kinds of weeds, especially smartweed, are also attacked.

The insect in many cases completely defoliates the trees in addition to causing severe damage by feeding on the early ripening varieties of fruit. In certain areas in New Jersey the loss of the fruit of early apples in 1923 amounted to about 15 per cent of the crop. In addition to the destruction by the adult beetles, the larvæ have damaged lawns, pastures, and golf courses through the feeding which they do on the roots of various grasses. Some injury has also been found to occur to strawberries, cabbage, and other plants which have been set in fields heavily infested with the larvæ.

The eggs of the Japanese beetle are white, translucent bodies, approximately one-sixteenth inch in diameter. They are deposited in the soil and hatch on an average in about 14 days.

The larva upon emerging from the egg is about one-sixteenth inch long. The larvæ feed on living plant roots, as well as on decaying vegetable matter in the soil. During the course of their development they molt twice, becoming full grown, or nearly 1 inch long, about the third or fourth week in September. The winter is passed in the larval stage, and during May they assume what is known as the prepupal form, a semi-inactive condition between the larval and pupal stages. The insect remains in the prepupal stage for about 11 days. The pupal stage lasts for about two weeks and the adult beetles emerge between the 10th and 20th of June.

The adult Japanese beetle is a brightly colored insect, varying in length from five-sixteenths to seven-sixteenths inch and in width from three-sixteenths to nine thirty-seconds inch. The color is bright, metallic green, except for the greater part of the wing covers, which are coppery brown. The elytra do not entirely cover the abdomen, but expose a row of five lateral and two posterior marginal spots, composed of white hairs. The legs are colored a dark, metallic, coppery green, varying in tint in different positions.

After emerging from the ground the beetles usually rest for a short period on various low-growing plants, after which they become more active and fly to their various food plants. Beetles have been observed to live on an average for about 44 to 46 days under cage conditions. In many cases the female beetles enter the soil late in the afternoon and deposit several eggs in the ground during the night. Egg-laying extends over a period of three to four weeks and, in all, between 30 and 50 eggs are deposited. It has been found that during the morning the beetles concentrate on low-growing plants, such as smartweed, and as the heat increases during the day they become more active and disperse to the taller plants until early in the afternoon, when they are abundant on the tallest oaks, elms, and maples. After 3 p. m. their flight is toward the ground and lower growing plants. The proportion of females to males is highest between 12 o'clock noon and 2 p. m., and lowest between 6 p. m. and 6 a. m.

The larva forms a cell in the soil slightly larger than its body and feeds on the fine rootlets at the top and bottom of the cell. It usually follows the course of the rootlets until these are consumed before attacking others. Examinations of the material consumed by the larvæ have indicated that fresh plant tissues constitute about 64.3 per cent of the material found in their alimentary canal.

Injury to sod land does not usually occur until there are at least 100 or more larvæ to each square yard. In some cases as high as

1,531 larvæ have been found to a measured square yard. They usually feed at a depth of one-half to three-fourths inch below the surface.

The injury caused by the feeding of the adult beetles is conspicuous and characteristic, and is comparable with the damage done by native leaf-chafers. Small plants may be defoliated, although on trees the leaves are usually skeletonized, causing them later to turn brown and drop. The beetles prefer to feed on foliage exposed to the direct rays of the sun, and little feeding has been observed in shaded woodlands. Usually the beetles commence to feed on the upper and outer foliage and work downward, and by the time one-half or two-thirds of the foliage on the tree in question has been consumed they leave and congregate on other plants. The beetles are extremely fond of green corn silk and the developing ear. Frequently ears have been noted on which the grains and husk were eaten for more than one-half the length of the cob.

The feeding habits of the beetles are variable and have been found to change somewhat from year to year. Some orchards which are heavily infested early in the season later become entirely free from the beetles and no further damage may be caused. The insects fly actively on clear, warm days, and there is considerable change in their feeding places from day to day.

The total life cycle of the Japanese beetle is one year, five-sixths of this time being spent in the soil as an egg, larva, or pupa. Having passed the winter in the soil, between 2 and 4 inches below the surface, the larvæ pupate during May, and transform to adults between June 10 and June 20. The beetles are present during a period of four months and are most abundant during July and August. A preference is shown by the females for sod land as a place in which to deposit their eggs; larvæ, however, have been found abundant in cultivated fields and orchards. The time of pupation and the average emergence time of the adults are 10 days to two weeks earlier in loam soils than in the pure sand types.

The Japanese beetle has spread outward at a rate of 10 to 15 miles each year. It is believed that the spread to date has been largely due to natural factors, and of these the flight of the adult beetle is the most outstanding natural agency of dispersion. Winds and storms probably play some part in the dispersion of the insects. The movement of infested farm products and soil in which larvæ occur is probably the most important means by which the beetle could be carried a long distance. During 1923 more than 32,000 beetles were removed from sweet corn consigned to New York from one New Jersey district. Passing vehicles also afford means of artificial dispersion of the insect, but probably not over as long distances as would be the case in shipments of infested produce.

Since its first appearance in 1916 no climatological condition has arisen which has offered any serious check to the numerical increase of the species.

Certain microorganisms are pathogenic to the larvæ of the Japanese beetle. In some cases it has been found that these play a rôle in the natural control of the insect. A few species of fungi have also been discovered which attack the larvæ of the Japanese beetle.

Several species of insects parasitic on the Japanese beetle in Japan have been imported for the purpose of establishing them in this country. One species (*Centeter cinerea* Ald.) was imported and released during the seasons of 1922 and 1923. In 1924 beetles were found over an area of approximately 12 square miles which had been parasitized by this introduced parasite. A species of dexiid (*Prosena siberita* Fabr.) which is parasitic on the larvæ of the Japanese beetle has been imported in large numbers, but no data have been collected as yet that would indicate whether it will become successfully established in New Jersey. Several species of Tiphia are being imported in small numbers, and attempts were made without success to introduce the Scolia wasp (*Scolia manilœ* Ashmead) and the moth lacewing (*Ithone fusca* Newm.). Several species of Carabidae (ground-beetles) have been found to feed on the larvæ of the Japanese beetle, and, to some extent, the larvæ of certain species of Tabanidæ (horse-flies). At the present time, however, there is no evidence of any decided increase in the numbers of various native predacious insects.

It was found that the beetles and the grubs form a portion of the diet of several species of birds, but not to such an extent as to offer any serious check to the multiplication of the insects.

Following the discovery of the insect in New Jersey efforts were made to eradicate it but these were unsuccessful and were eventually given up. Quarantines have been maintained for several years past restricting the movement of nursery stock as well as the movement of farm produce. A scouting force is maintained during the summer, which operates over the eastern part of the United States in order to determine the spread of the insect from year to year.

A large amount of work has been done for the purpose of discovering methods of control of the larvæ where they occur in sodlands or in the soil about the roots of various types of plants intended for shipment outside the regulated area. A practical means of destroying the larvæ in golf greens has been devised, consisting of treating the soil with a dilute solution of carbon-disulfide emulsion. The emulsion is prepared by mixing 1 part by volume of cold-water-soluble resin-fishoil soap, 3 parts of water, and 10 parts of carbon disulfide. The soap and water are mixed in a churn or ice-cream freezer until an even mixture is obtained, then the carbon disulfide is added and emulsified. One quart of the emulsion thus obtained is stirred into 50 gallons of water and the resulting mixture is applied at the rate of 3 pints to each square foot of turf. Various methods have been worked out for the destruction of the insect where it occurs in the soil about the roots of nursery stock. Most of these are based on the use of carbon-disulfide emulsion and an emulsion of wormseed oil applied in dilute form to the soil.

It was found during the early experimental work that the beetles were repelled by the presence of arsenate of lead on the foliage of plants. Advantage was taken of this fact, and many growers have successfully protected their plants through the application of this material in fairly large quantities. In order to prolong the stay of the spray material on the foliage, as well as to increase the percentage of mortality obtained, mixtures of arsenate-of-lead paste were developed, containing stickers and spreaders of certain types,

which have given excellent results. Not only has the killing obtained been greater in many cases but the spreading and sticking qualities of the spraying mixture have been greatly improved. At the present time these mixtures of arsenate of lead are the most promising insecticides for use against the adult beetle. Until these preparations are placed on the market the following recommendations have been made for the protection of various crops:

Early and late ripening varieties of apples should be sprayed with a mixture of 3 pounds of arsenate of lead and 2 pounds of flour (gluten content at least 12 per cent) to 50 gallons of water. In order to protect the foliage and fruit from the attacks of the beetles it is necessary to have the spray applied before the plants become infested. In general the spray should be on the plants by June 25. A thorough job of spraying must be done in order to protect the plants and control the beetles, and it is necessary to maintain a film of the spray on the foliage throughout the season when the beetles are present. This spray may also be used to advantage in the case of cherries, grapes, and ornamental trees.

Peaches of the Carman variety, or varieties which ripen later in the season, may be sprayed with 1½ pounds of arsenate of lead, 2 pounds of flour, and 3 pounds of unslaked lime to 50 gallons of water. In most cases the Japanese-beetle spray can be applied on late-ripening varieties, provided the spraying is completed by June 25, or a month previous to the time of harvesting. As in the case of other plants, a thorough application of the spray must be made in order to give adequate protection to the foliage.

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